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# TRANSACTIONS

OF THE

# AMERICAN INSTITUTE

OF

# ELECTRICAL ENGINEERS.

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# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 22, 1901.

The 152d meeting was held this date at 12 West 31st Street, and was called to order by President Hering, at 8.30 P. M.

THE SECRETARY:—At the meeting of the Council this afternoon, the following Associate Members were elected:

| Name. | Address. | Endorsed by |
|---|---|---|
| ALBIN, HENRY ALLISON | General Manager and Electrical Engineer, Concord St. Railway, Concord, N. H. | Chas. R. Cross.<br>J. B. Smith.<br>S. B. Paine. |
| BULL, ROBERT WILSON | Electrical Engineer, The New Jersey Zinc Co., (of Penn.) Palmerton, Pa. | Gano S. Dunn.<br>F. V. Henshaw.<br>Horace Dowie. |
| COOKE, GEORGE A. | Electrical Engineer and Supt., Hawaiian Electric Co., Honolulu, H. I.; residence, Chicago, Ill. | Wynn Meredith.<br>A. M. Hunt.<br>A. Gartley. |
| EDMANDS, SAMUEL SUMNER | Assistant in Electrical Engineering, Ohio State University, Columbus, O. | F. C. Caldwell.<br>H. B. Smith.<br>E. E. Brown. |
| HOWE, WINTHROP KEITH | Assistant Engineer, Taylor Signal Co., 256 Delaware Ave., Buffalo, N. Y. | H. H. Wait.<br>E. P. Warner.<br>V. R. Lansingh. |
| JOHNSON, WALLACE CLYDE | Chief Engineer, The Niagara Falls Hydraulic Power and M'f'g. Co., Niagara Falls, N. Y. | J. F. Kelly.<br>I. R. Edmands.<br>S. B. Winchester. |
| MUDGE, ARTHUR LANGLEY | Electrical Engineer, Grand Trunk Railway Co., Montreal, Canada. | R. B. Owens.<br>P. G. Gossler.<br>R. M. Wilson. |
| PERRY, JOHN | President of I. E. E. (England) 84 Palace Gardens Terrace, London W. England. | W. J. Hammer.<br>Ralph W. Pope.<br>Carl Hering. |
| ROCKWOOD, DWIGHT CARRINGTON | Student, Westinghouse Elec. & M'f'g Co., Box 104, Edgewood Park, Pa.; residence, 954 Main St., Buffalo, N. Y. | Chas. F. Scott.<br>John S. Peck.<br>H. L. Wallau. |

| | | |
|---|---|---|
| SPARKS, CHAS. PRATT | Chief Engineer, The County of London Electric Lighting Co., Surrey, England. | Wm. J. Hammer<br>Ralph W. Pope.<br>Carl Hering. |
| STRONG, JAMES REMSEN | President, The Tucker Electric Construction Co., 35 South William St., N. Y.; residence, Short Hills, N. J. | H. A. Sinclair.<br>T. C. Martin.<br>W. D. Weaver. |
| SWINTON, ALAN ARCHIBALD CAMPBELL | Consulting Electrical Engineer, 66 Victoria St., London S. W. England. | Wm. J. Hammer.<br>Ralph W. Pope.<br>Carl Hering |
| THOMAS, JOHN WILLIAMS | Construction Engineer, Electric Storage Battery Co., Hokendauqua, Pa. | Louis Duncan.<br>C. T. Hutchinson<br>Leonard Waldo. |
| THOMSON, GEO. ANDROS | Special Agent, The Adams-Bagnall Electric Co. 26 Cortlandt Street, New York; residence, Somerville, N. J. | J. J. Bellman.<br>F. M. Pedersen.<br>Horace Dowie. |
| VAN VLEET, ROY MITCHELL | Student, Westinghouse Elec. & M'f'g Co., Edgewood Park, Pa.; residence, Port Huron, Mich. | H. L. Wallau.<br>Chas. F. Scott.<br>Jno. S. Peck. |

Total 15.

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The following named Associate Member was transferred to full membership:

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Approved by Board of Examiners. February 8th, 1901.

| | |
|---|---|
| ARTHUR L. HADLEY, | Electrical Engineer, Fort Wayne Electric Works, Fort Wayne, Ind. |

At the meeting of the Council this afternoon, the following names were selected as the Council nominations for the coming election.

For *President*, Charles P. Steinmetz; for *Vice-Presidents*, Samuel Sheldon, George F. Sever, Michael I. Pupin; for *Managers*, John W. Lieb, Jr., Charles F. Scott, Samuel Reber, W. E. Goldsborough; for *Treasurer*, George A. Hamilton; for *Secretary*, Ralph W. Pope.

THE PRESIDENT:—The paper of the evening which is next in order is on the "Distribution and Conversion of Received Currents," by Henry Gordon Stott. I will call upon Mr. Stott to read his paper.

[See page 237 April issue.]

DISCUSSION.

MR. GANO S. DUNN:—The portion of the paper referring to the use of rotary converters and motor generators was particularly interesting to me, because of some recent interest I have had in that matter. I notice on page 250, near the bottom, that after giving the different efficiencies of these two arrangements for transformation, Mr. Stott gives the difference in first cost as about 19 per cent. Now, two-phase rotary converters have an increased capacity over the corresponding direct current generator, and three-phase machines a still greater increase, and my figures have led me to believe that the difference in cost between motor generators and rotaries even on the two phase basis is greater than 19 per cent. I should like to ask Mr. Stott what was the mechanical arrangement of the motor generators on which that cost was figured. Was it simply a motor coupled to a generator, or were two armatures on one shaft supported by only two bearings instead of four, and were there any other features that would throw light on the small increase in cost relatively to the rotary converters?

MR. STOTT:—In reference to the small difference of cost, I should say that all this work is three-phase work, and that the price of rotaries include static transformers, whereas the price of motor generators does not.

After leaving the transformer house at Niagara Falls everything is three-phase from there onwards. The difference of cost was taken from actual figures, and I do not know exactly what to ascribe it to unless that the speed of the rotary converter was comparatively low, and the comparison probably would have come out more even, or rather a greater difference, had the speeds been more alike; that is to say, the speed of the rotary converter, as I remember, was lower than that of the motor generator set.

MR. CALVIN W. RICE:—I would like to ask if any data have been obtained in these experiments on the watts lost per duct foot in multiple duct construction?

MR STOTT:—In reference to Mr. Rice's question, that is not one that is taken up in this paper, and I cannot answer that question off-hand, but a great number of experiments were carried on at Niagara Falls, the results of which I have not with me to-night, but I know, speaking from memory, it came out that when the ducts were in a greater number than 25, and were all filled with cables, that is to say, three-conductor three-phase cables, that it became almost impossible to get rid of the heat without some special means of ventilation. The test was made on conduits as actually laid with wires pulled through them, and run up to a temperature corresponding to what the dissipation of heat would have been with a three-conductor 2200-volt cable, and for that reason instead of supplying a large factory near the

power house at 2200 volts it was decided on the strength of those experiments to supply them at 11,000 volts to get rid of this loss of energy in the cables. I am sorry I have not got the figures.

MR. RICE:—I would like to ask if in practical operation you run paper cables at a higher temperature than you do rubber?

MR. STOTT:—The paper cables have only just been put in. They only went into operation about a month ago, so that they have not been forced at all.

MR. C. P. STEINMETZ:—I would like to ask Mr. Stott whether with the types of switches employed in the different stations, the open air long break switch, and the oil switch, he has noticed any difference in the action of those switches on the circuit, that is, whether sometimes one switch is more liable to cause rupture of the cable than the other, if such rupture occurs at all.

MR. STOTT:—I do not believe that there has been enough difference in the behavior of these switches to really be noticeable; that is to say, these interruptions to the cables have usually happened during the time the cable was in service, and not at the time of the interruption of the circuit. There is one point we noticed in cables breaking down, that the breakdowns almost invariably came from one to three days after an interruption. That is to say, the current had been thrown on that cable at full pressure, and we were afraid that some resonant effects had taken place, because an examination of the statistics of break-downs showed in almost every case that the break-downs occurred from one to three days of the time when the cables had been out of service and had been suddenly put into service at full pressure.

MR. ELIAS E. RIES:—Mr. Stott states on page 250 that the largest user of power in Buffalo is the International Traction Company, which receives a total of 7,000 horse power in five sub-stations, which is first transformed from 11,000 volts to 375 volts, and then converted in rotary converters to 600 volts direct current, for supplying continuous-current railway motors. I would like to ask Mr. Stott whether or not the International Traction Company has ever attempted to use the alternating current for the direct operation of motors on cars instead of first converting it into direct current.

MR. STOTT:—No; that attempt has never been made.

MR. RIES:—At our last meeting Mr. Hammer gave us a description of several electric railway installations in Europe in which the motors were operated by alternating currents, and it would be interesting, I believe, to the members present to hear of some tests made in this country with that object in view. Perhaps, our friend Mr. Steinmetz, might be able to enlighten us on that subject.

MR. STEINMETZ:—I can do that very well, because I have made very many tests on the use of three-phase motors on railroad

cars. The first tests were made in 1894, running a trolley car around the factory yard, and we have run the car many times since, and tried various types of motors on our experimental railroad track, and have satisfied ourselves entirely that with the three-phase motor on a car you can get a rapid acceleration, you can get any starting torque you want, you can do anything you want to do, but the motor is in its electrical and mechanical character, essentially a shunt motor. It has a torque proportional to the current, and independent of the speed at constant field excitation. That is to say, if you want to start you require at the moment of starting the same current for a given torque as you require when running at full speed, and the rest of the power corresponding to reduced speed is merely wasted in the rheostat. Shunt motors, continuous current, have been tried a number of times in electric railroad service, and have always failed, and that was the reason why the three-phase railroad motor has not been introduced. It is decidedly inferior in starting, and in running at low speed, and in acceleration, to the continuous current series motor. Now, there is undoubtedly a considerable advantage in the induction motor for a railroad car, because you can eliminate the rotary converter and the substations, and can install stationary transformer stations. It has the disadvantage that you need two trolleys. There is in existence a double trolley road in the United States, and claimed to be very satisfactory, but I do not think that a second one has ever been built. You can imagine how beautiful it would be in the center of a city to run a double trolley system. The three-phase motor nevertheless might come in use going from city to city, because there you have no switches and crossings. You do not need to start and stop so frequently. The only trouble is these suburban roads always run into a city, and you do not want to dump the passengers at the outskirts of the city and have them wait for the next city car, as necessary if you changed to direct current and different motors there. That is one disadvantage of the three-phase motor.

Then the three-phase induction motor has a power factor. In railway service you could not run a thirty-second of an inch air-gap between the rotary and the stationary member of the motor. You have to have a little more generous air-gaps for mechanical reasons. The power factor is some 80 per cent. with the usual induction motor air-gap. You can imagine where that power factor goes to with a larger air-gap. That means so much more current over the trolley line, not only so much more current but lagging current, which causes so much more drop in the reactance of the line in addition to the resistance drop. In continuous current trolley lines we sometimes have enormous drops. If you have a heavy load on the end of a feeder, from 500 to 600 volts that you start out with, the voltage may go down even to 200 or 300 volts. Well, it means the cars go along slowly, but still they

go, and they give any torque you want in starting. With the induction motor, the torque is proportional to the square of the voltage. Hence, if you run the induction motor trolley line at 600 volts average potential, and the voltage is 300, the car will not start. You get over that to a certain extent by raising the voltage on the trolley. But then you have the deviation from standard practice. Everybody knows what the 550-volt trolley does, and nobody knows what the 3,000-volt trolley will do, except on paper, and on experimental lines. All these difficulties and objections of special arrangements and new untried methods in practice have to be considered. Still the system would be introduced if there were any essential compensating advantages. Theoretically you can undoubtedly see some points wherein the three-phase road is really superior. Since I experimented in 1894, I thought, and all my friends agreed with me, that it would be very nice to install a three-phase railroad somewhere. So I and all other railroad engineers with whom I am acquainted have endeavored to find a place where we really have a reasonable excuse to install a three-phase railroad. Once we nearly had one, and at present we again see a chance where we might install one, where there is really a good reason for using it, but thus far I have not installed any. Taking all into consideration, the wide range of speed and power required in railroading, rather militates against induction motors, which give full efficiency only at full speed.

Still, there may be special cases, and I hope still to live long enough to find a few where induction motors are preferable. For instance, where you climb a grade running up the Rocky Mountains, one side up and the other down, or anything of that kind, where you can give uniform speed running down hill, running a little above synchronism, and therefore have the induction motor act as generator on the down grade; you have the advantage that you do not wear out the brakes. However, the experience of the Jungfrau Railroad, which, as you know, was built as a three-phase railroad, was not very favorable. They have very few cars running, and once in a while it happens that a car was running down, returning power, and no car going up to use the power, and the ultimate outcome was that they put in some remarkably complicated arrangements for electrically consuming the power. But then I fail to see what advantage a three-phase current has in this case.

It is true in Europe there are a number of three-phase railroads; but we cannot draw any analogy from that, for the railroad conditions are very different there. The rotary converter is absolutely unknown to European engineers. They have never found out what that thing is. Rotary converters are being rapidly introduced in Europe,—but the engineers there know nothing about them excepting that they believe they are no good. All the converters there are American made, or made at branch factories of American com-

panies, and so where the power for a railroad has to be transmitted a long distance as polyphase current, the rotary converter being unknown, the Europeans have used three-phase motors on the car. Here in the States the rotary converter was installed and put into commercial service, in 1894, in the early days of long distance transmission, and became so familiar to everybody that when long distance transmission for railroads came into consideration, the ordinary standard continuous motor was used, and nobody was forced to get up a new system of railroad motors, which offered no compensating advantages, and so the three-phase railroad motor has not been introduced here, although I hope we might still see some experimental plants.

THE PRESIDENT:—Mr. Steinmetz' account was very interesting, but I think he is mistaken in one or two points. I do not think the Jungfrau railroad is a failure. When I visited it last summer I was told quite the contrary[1]; the part that is now in operation is paying excellent returns for the investment in that part. The company is, of course, not paying any dividends yet, because it is continuing the construction of the road. The constructors worked all the previous winter at it, and this year I believe they intend to work all summer, too. Concerning that device for running down hill which Mr. Steinmetz referred to as being very complicated, I would like to explain that it is used only as a safety device, so as to be able to run down hill in case the continuity of the trolley wires or contact with them, is broken. Moreover it is at present used only on one of the four locomotives as an experiment; with the system used on the others, if a car goes down hill and something happens at the power station or to the trolley lines, so that it could not send the power back into the trolley lines, it would have to descend with the aid of the brake-shoe, which is objectionable. It is to meet this emergency that this system of exciting with continuous current is used. Moreover, it is not complicated in the least; it is simply the addition of a very small continuous current dynamo, belted to one of the motors. In other respects the plant is exactly the same as before. It cannot be said therefore that it is a very serious complication.

Concerning rotary converters, Mr. Steinmetz was not correct in saying that they are absolutely unknown to European engineers. They are known and are used there, though much less frequently. The foreign engineers differ with us in estimating the relative advantages of the rotary converter and the motor-generator. I saw a large rotary converter of German manufacture, installed in the large, new Berlin station, and the engineer who designed the installation said that if he had to do it over again he would install a motor-generator. That rotary converter was also of interest in that it could be regulated for vol-

[1] Since this discussion took place I have been informed by a Swiss electrical engineer, who is in a position to know, that this railroad will unquestionably be continued, and that the reports of its failure were started by those who wanted to buy a controlling interest in the stock.

tage. It was coupled on the same shaft with what might be called an alternator which was excited by the continuous current. The alternating current, before it went into the rotary, passed through this alternator and by variously exciting the field, the alternating current could be boosted up, or lowered in voltage, and in that way the voltage of the continuous current could be regulated without passing it through a second commutator.

MR. RIES:—I would like to ask Mr. Steinmetz whether it is not mainly due to the fact that direct-current motors in this country are standardized and a regular article of manufacture, that progress in the development of alternating current railway motors is more backward here than it is abroad, rather than to the many alleged disadvantages of such motors which he has stated. We know that there are a great many losses and complications in the methods which are practiced at Buffalo, as Mr. Stott showed in his paper to-night, and wherever else the alternating-direct transmission system is installed. It has been the aim of electrical engineers to overcome those losses and to simplify the equipment so as to avoid the necessity of having so many intermediate transformations and so much attendance at rotary sub-stations, etc., which the static transformer would eliminate. I am under the impression, at least it has been so stated, that there is a lack of serious effort made here on the part of the larger manufacturing companies to avail themselves of the opportunities presented by the use of alternating current railway motors for purely selfish reasons, rather than owing to their few disadvantages. The question of double trolleys, etc.,—three-conductors, in the case of multiphase currents—would not be so serious a matter in large cities where the underground conduit is used; the track could be used as the third conductor very readily, and the other disadvantages mentioned are not deterrent. The question is whether or not the fact that direct current motors have become standardized, and are used so extensively on existing railway cars as to cause a reluctance on the part of manufacturing concerns to such a change, is not the principal reason that the United States is so far behind Europe in this respect.

MR. STEINMETZ:—There is undoubtedly in the relation between standard apparatus and special apparatus, a good deal of cause for the customer to fight shy of three-phase motors; but as far as the large manufacturing companies are concerned, there is no disinclination on their side against the three-phase induction motors on railroads. On the contrary there is a very great tendency toward that practice, and it has been pushed to a good extent. I am quite sure that the Westinghouse company has been trying, just as the company with which I am connected has for a number of years been trying, to install three-phase induction motors on railroads.

I may, for instance, state that an American company is at present installing a three-phase induction railroad in northern Italy, not

in America. The Italians wanted three-phase, and so they got it. But if it were this country, I would not recommend three-phase. I do not see any reason, because continuous current could do just as well, and better; but this road is being built, and I am very glad of it. Another instance we had some years ago, where we wanted to build a three-phase railroad at cost price, and see it go. But at the last moment the customer put on the continuous current. If you come to the underground conduit, you must consider that even at 20-cycles, the ordinary iron rail offers against an alternating current an impedance which is from three to five times the ohmic resistance, which is not negligible. Still there is really no disinclination by American designing and consulting engineers, but all have been very favorably inclined to the three-phase induction motor for railroads, only there was no case in this country where it could be conscientiously recommended in preference to the continuous current motor.

Mr. Joseph Sachs:—I think the acceleration of the induction motor in this case is such that we have ran ahead of the paper, and rather lost it in the background. I think that while we have all been most intensely interested in Mr. Steinmetz's discussion of the induction motor operation, we would be far more interested, if that were at all possible, to hear his discussion of the proposition that he had already mentioned, namely, the operation of protective devices on such systems as Mr. Stott has mentioned.

It seems to me that in the paper two peculiar forms of high potential protective circuit-opening devices are mentioned, and Mr. Steinmetz has already asked the question whether there was any difference in effect between the operation of a long drawn out arc circuit-opening device, and that of the quick circuit-opening device. I think that is a question of intense interest to us all, and if Mr. Stott cannot give us detailed information thereon, that is, with relation to the effect of such circuit-opening devices, upon transmission and generating and translating machinery, perhaps Mr. Steinmetz can, or some of our other members may be able to do so. I should very much like to hear from Mr. Steinmetz his opinion, regarding, for instance, the relative supposed effect of long drawn out arc circuit-opening devices over those that operate instantaneously.

Mr. Steinmetz:—Regarding this question I may say that in the comparison of the long drawn out circuit-breaking device and the quick break—that the quick break is the air switch, and not the oil switch. It is frequently assumed that if you draw a long arc in the air, that there is a slow break in the circuit. That is not the case. There is no break quicker than the break in open air. Metal vapor being of very low resistance can draw an arc two or three feet long, having a drop of not more than a few hundred volts. If in a high potential circuit you draw an arc of

three or four feet, there is hardly any voltage across the arc, until it breaks. But the break is extremely quick. A friend of mine has made some very nice photographic investigations of the nature of the break in a high potential circuit, with capacity in shunt, and found that a short circuit across a high potential circuit ruptures itself with extreme rapidity.

When the oil switch was experimented with, I was very greatly afraid of it due to the quick break in the oil. Experience and a very careful investigation on high voltage circuits has shown that the break of the oil switch at very high voltage, three, five or ten thousand, is not a quick break. Liquid is practically incompressible, and therefore the gas bubble which is formed there stands under enormous pressure and holds the arc up to the next zero value of current. At the next zero value of current the liquid pressure blows out the arc. It seems to be the action of the oil switch to hold the circuit up to the next zero value and then extinguish it. So that other things being equal, the probability is that the open air break is more dangerous and destructive than the oil break. Now, I have no complete experimental record of that except that in investigations which were made incidentally on the same plant at Niagara Falls, described in the paper, with 5000 horse-power behind. When trying a number of different breaks I found that the only switch which would open the circuit with the resistance and inductance in series, which never gave a rise of voltage, was the oil switch. That is not quite conclusive, because all I had was ordinary resistance and inductance, but no capacity. The conditions may change as soon as capacity enters. But I know that in all inductive circuits, with negligible capacity, the air switch is more dangerous than the oil switch. It may then be assumed in the absence of more complete data that the oil switch is the safer one, even in other cases.

I have investigated that lately, and I shall at one of the next meetings read a paper on the theoretical investigations of these high voltage phenomena which may occur in transmission lines during a sudden change of circuit conditions, as closing the circuit on the lines, or opening it, or short circuiting it.

MR. CALVIN W. RICE:—I would like to ask if the speaker of the evening has followed the articles written by Mr. Mordey on "Cable Work," and has had any experience along the same lines.

MR. STOTT:—I do not know what articles you refer to.

MR. RICE:—The recent articles in *Engineering*, speaking about capacity in cables, and the amount of charging current.

MR. STOTT:—I have not read the articles in question.

MR. JOHN W. LIEB, JR.:—I would like to ask Mr. Stott in regard to the reference he makes to the cables, on page 248. He states that a rubber insulated cable with 9/32″ wall, 30 per cent. pure Para is perfectly reliable for 11,000 volts; but that 8/32″ insulation even with a higher percentage of pure Para is not.

It seems to me that, with the difficulties which are encountered in the manufacture, and which can quite readily give rise to differences in thickness of dielectric greater than one-thirty-second, where such a deduction is drawn, it would seem rather to indicate that even the 9/32″ cable was perhaps insufficiently insulated, and that on the whole for such a high voltage there was not a sufficient margin of safety, and that the margin was sacrificed by the slight reduction of 1/32″. I should like to know whether that deduction was based on something else than the mere difference of 1/32″, because it seemed to me that with the variations that are likely to take place in manufacturing such a cable there ought to be a greater margin than one-thirty-second of an inch between an insulation thickness sufficient to secure perfect reliability, and one that is not. In this light I do not understand the conclusions arrived at by the author.

MR. STOTT:—With reference to these remarks, as stated in the paper, these are the general conclusions that we have been able to draw from the actual number of breakdowns during a period of three years. These cables have been used over three years, and were made by very reliable manufacturers, the best manufacturers probably there are in the United States, and we have had more breakdowns on that 8/32″, although it has been in a year less than the other two, and naturally we began to think that the puncture resistance was not so great with 8/32″ as it was with 9/32″, and there does seem to be a distinct difference, and that the 1/32″ makes a marked difference. These are from a record, very carefully kept, of all breakdowns. I am sorry that I cannot say whether it broke down to ground or between conductors, because after an 11,000-volts burn out there is not anything left to tell. But 1/32″ extra insulation seems to give very greatly increased reliability. That is, after the cable has been in use for a long time. By a long time I mean several months. There is another fact that possibly may have something to do with it, and that is whether 40 per cent. of pure Para is not too pure and deteriorates under pressure. Some experiments are being carried on that I know of as to the deterioration of insulation under a continued high pressure, and the loss of insulation, that is to say, the megohms as measured by the galvonometer, after a continuous application of high pressure, is very distinct. That is to say, there is a distinct fall in insulation as the test is continued. If at the end of ten days the insulation is 400 megohms, at the end of twenty days it will be down to perhaps half of that value and keep on decreasing. These experiments are not yet complete, but the tendency has been very marked in that direction, and apparently (from these experiments being carried on) the purer rubber is going that way faster than the less pure.

MR. CALVIN W. RICE:—I would like to ask if the dimensions of the cable are those in the specification or the dimensions

observed by inspection of various lengths, and if 9/32″ means the least dimension that was observed in any of the product; also is the 30 per cent. cable made by one maker and the 40 per cent. made by another maker, and if there were tests made to determine whether there was exactly 30 per cent. or 40 per cent.

MR. STOTT:—In reply to these questions, the thickness of the wall was quite carefully measured, and these are the means of a great many measurements, so that it may be taken that these represent the mean thickness of the wall. As to the percentage of pure Para, that we have got to rely upon the manufacturer for. As you know, the analysis of rubber is an extremely difficult thing to perform, and you can get almost any result you like with those hydrocarbons.

MR. RICE:—I would like to ask if these breakdowns occurred mainly in the cable or in the joints, and as to the possibilities of mechanical injuries as a cause for the breakdowns, or was the cable so destroyed that you could not tell whether there was mechanical injury or not.

MR. STOTT:—The breakdowns in almost every case in the cable referred to occurred in the middle of the section, or at least ten feet from a manhole, and the result was such that you could not tell anything about it. It just blew the whole cable to pieces.

MR. H. D. REED:—The conditions are so great and varied with the rubber in cables that I should think it would be necessary to determine whether that 1/32″ was the cause of these cables breaking down, that is, if a thirty-second less, rather than the treatment of the rubber itself, was the cause. Now, there are a great many grades of pure Para rubber, and the age of the rubber has considerable to do with it, also the length of time that the rubber is dried and cured before it is compounded, and the cleanliness of the rubber is a feature that enters very materially into the manufacture of cables. Now, I would be inclined to think that an 8/32 wall of 40 per cent. rubber would be safer than 9/32 of 30 per cent. rubber. From the experience I have had with cables, especially after a lapse of time, 40 per cent. rubber will be very much more durable than the 30 per cent. compound.

MR. SACHS:—I am not familiar with the cable practice and transmission through cables, but it would seem to me, and it probably seemed to a great many others this evening, that the difference between 8/32 and 9/32 of an inch of insulation on a high potential cable is very small. The tendency to-day in engineering practice is to make everything "fool proof," and I think it also is in a great many cases necessary to make it mechanically and also electrically "fool proof." I should say if 8/32″ of insulation on a high potential cable were bad, that 9/32″ were almost equally bad, and if trouble was experienced with the 9/32″, I should add one or two more thirty-seconds of rubber, and get a little additional factor of safety.

MR. STOTT:—I would reply to Mr. Sachs' remark—there is another factor besides the factor of safety that enters into the question, and that is the matter of cost. A cable of 1/32″ extra insulation would probably send up the price 25 cents a foot.

MR. SACHS:—Quite true. But I should think that the deterioration would in time affect the 9/32″ just as much as it previously did the 8/32″, that it was simply a question of time before the 9/32″ broke down, and if you added a few more thirty-seconds it would take a little more time to break down, and thus you might continue the life of the cable. That is simply my opinion of the matter. As I said, I am entirely unfamiliar with the practice.

[Adjourned.]

# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 26, 1901.

The 153rd meeting was held this date at 12 West 31st Street, and was called to order by President Hering, at 8:20 P. M.

THE SECRETARY :—At the meeting of the Executive Committee this afternoon, the following Associate Members were elected:

| Name | Address | Endorsed by |
|---|---|---|
| ANDERSON, DOUGLAS SMITH | Professor of Electricity and Electrical Engineering, University of Mississippi, University, Miss. | Brown Ayres.<br>Harris J. Ryan.<br>Edw. L. Nichols. |
| BREWSTER, WALTER SCOTT | Electrician, Standard Underground Cable Co., 205 Market St., Perth Amboy, N. J. | H. W. Fisher.<br>A. J. Rowland.<br>R A. Fessenden. |
| BURNETT, JAMES AUBREY | Draftsman and Designer, Royal Electric Co., 94 Queen St., residence, 19 Shuter Street, Montreal, P. Q. | P. G. Gossler.<br>R B. Owens.<br>Ernst J. Berg. |
| CLARK, FARLEY GRANGER | Electrician in charge 96th St. Power Station, Metropolitan St. Ry. Co., 96th St. and 1st Ave., residence, 489 Manhattan Ave., New York City. | W. N. Ryerson.<br>P. Torchio.<br>J. J. Mahoney. |
| CLOUGH, DWIGHT EDWARD | Electrician, Buffalo and Lockport Railway, Lockport, N. Y. | P. Eskil Berg.<br>H S Webb.<br>C. E. Gifford. |
| GILLIS, HARRY ALEXANDER | General Superintendent, Richmond Locomotive Works, Richmond, Va. | Gano S. Dunn.<br>Wm. S. Aldrich.<br>Thos. V. Bolan. |
| HAUBRICH, ALEX. MICHAEL | Electrical Engineer, Central Union Telephone Co., 1809 Ashland Block, Chicago, Ill | H. S. Carhart.<br>S. G. Mc Meen.<br>B. J. Arnold. |
| HODGES, WILLIAM LEMMON | Asst. Engineer, The Keystone Telephone Co., 750 Drexel Bldg., residence: 8453 Woodlawn Ave., Philadelphia. | Louis Duncan.<br>J. J Carty.<br>Henry Floy. |

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| HOPTON, WALTER EDWIN | General Superintendent Cincinnati Edison Electric Co., Cincinnati, O. | A. N. Mansfield.<br>F. E. Idell.<br>W. K. Archbold. |
| KILGOUR, MARTIN HAMILTON | Borough Electrical Engineer, Corporation Electric Works, 2 Church Street, Cheltenham, England. | W. H. Preece.<br>C.H.Wordingham<br>W. M. Mordey. |
| LEEDS, MORRIS EVANS | Managing Member of the firm, Morris E. Leeds & Co., 259 North Broad St., residence, 3221 N. 17th St., Philadelphia, Pa. | Edwin J. Houston<br>Chas. J. Reed.<br>Carl Hering. |
| MC BERTY, FRANK R. | Telephone Engineer, Western Electric Co., Chicago, Ill., residence, Evanston, Ill | T. D. Lockwood.<br>I. H. Farnham.<br>F A. Pickernell. |
| MONRATH, GUSTAVE | Engineer and Superintendent, Grace & Hyde Engineering Co., residence. 26 E. 42d St., New York City. | C. G. Armstrong.<br>H B. Coho.<br>M. Coster. |
| ROBERTSON, JAS. MCCALLUM | Superintendent, Power Department, The Royal Electric Co., Montreal, P. Q. | Norman Ross.<br>P. G. Gossler.<br>Ralph D.Mershon |
| THORNTON, KENNETH BUCHANAN | Superintendent Line Department, The Royal Electric Co., residence 840 Dorchester Street, Montreal, P. Q. | P. G. Gossler.<br>H. R. Leyden.<br>R. M. Wilson. |

Total 15.

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The following Associate Members were transferred to full Membership.

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Approved by Board of Examiners, March 18th, 1901.

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| BUCK, HAROLD WINTHROP | Electrical Engineer, Niagara Falls Power Co., 170 Buffalo Avenue, Niagara Falls. |
| BURGESS, CHARLES FREDERICK | Assistant Professor, Electrical Engineering, University of Wisconsin, 609 Lake Street, Madison, Wis. |
| FISHER, HENRY WRIGHT | Electrician and Director of Electricity and Chemical Laboratories, The Standard Underground Cable Co., Pittsburg, Pa. |
| HAFER, GEORGE, JR. | General Superintendent and Electrical Engineer, Cincinnati Gas Co., Electric Department, Cincinnati, O. |
| KENAN, WILLIAM RAND, JR. | Traders' Paper Co. Lockport, N. Y. |
| MURPHY, JOHN | Superintendent, Power Houses, The Ottawa Electric Co., Ottawa, Ont. |
| SPRINGER, FRANK WESLEY | Assistant Professor Electrical Engineering, University of Minnesota, Minneapolis, Minn. |

The President announced that the Council had prepared and now submitted in writing an amendment to the Constitution, which would be brought up for consideration at the Annual Meeting May 21st.

Dr. Samuel Sheldon:—Mr. President, before those amendments are read, I would like to make a motion—inasmuch as we have two papers for this evening—that Mr. Dunn make a digest of the amendments and present to us the radical changes, omitting those parts which are common to both Constitutions. [Carried.]

Mr. Dunn having outlined the proposed changes in the Constitution, it was voted that the new Constitution, as revised by the Committee, be printed and distributed to the membership before the next meeting.

Prof. Harris J. Ryan then presented the following paper on "The Transformer for Measuring Large Direct Currents."

[See p. 265, April issue.]

## Discussion.

The President:—Professor Ryan's ingenious arrangement is to me one of the most novel departures in measuring instruments that I have seen for some time. The idea of using a transformer for direct currents would not be likely to suggest itself to many, and the way in which he has solved the problem of thus applying a useful property of transformers, is certainly extremely ingenious.

The arrangement which he describes must naturally compete with the use of a standard low resistance and a milli-voltmeter. In his paper he has not brought out the advantages which his method will have over this older one, but I presume he will make this clear in the discussion. The paper is open for discussion.

Mr. George T. Hanchett:—I do not wish to be understood as criticizing, but rather asking for information. There are one or two points which I would like to have brought out. I understand, turning to Fig. 1, that the alternating current voltage used to excite the coil A is obtained by means, I presume, of a sleeve carrying two slip rings, which are respectively connected with the two halves of the two-part commutator adjacent. Now, if a dynamometer instrument were placed upon the terminals of the coil A, a certain deflection would be noticed. As the commutator began to turn, there would be times when the coil A was not connected with the circuit at all, for if the brushes were allowed to bridge between segments 1 and 2. it would constitute a short-circuit between the rings 1 and 2. This introduction of a series of short periods of no voltage on the coil A, would, it seems to me, materially affect the deflection of the dynamometer instrument connected across its terminals, and similarly affect the voltage obtained at the slip rings 3 and 4, and therefore the maximum deflection of the galvanometer or instrument G, would depend, not only on the permeability of the core C, but on the speed of the commutator, which should therefore be a constant quantity. Am I right in that understanding?

Professor Ryan:—If I may at this time answer the two points—first, as to the matter of bridging over the segments mentioned, it will be noted that the reversal of the direct current occurs at that point as described, in the first commutator. The galvanometer is connected firmly at that very instant, to the middle of the two sectors on the galvanometer commutator. It is just at the instant of the reversal of the direct current that you get electromotive force. There is therefore no trouble of the character which may be thought of as possibly occurring because of the short-circuiting during this short contact of the segments.

Then as to the speed of the commutator. It is true the electromotive force depends entirely on that speed. Nevertheless the observer at the water rheostat is in full touch with any variation of speed that may be occurring in the driving mechanism

for these commutators; he is constantly running the water rheostat handle up and down, and he is entirely conscious of any change in speed that there may be on the part of the driving mechanism or the commutators, or on the part of the machinery that is developing the current. One cannot tell at the galvanometer G in this figure, and at the water rheostat, which cause it may be—either or both, for that matter, but you have entirely at your control the means for distinguishing between a maximum deflection that has come from your own act of adjustment of current, or from that which is due to the upward or downward drift of speed. That is a point, however, which actual experience with the method can only bring out, the conviction that this feature is all right.

MR. GANO S. DUNN:—On page 279, Professor Ryan says: "Where there are periodic and momentary fluctuations of the heavy current, the balancing current will be drawn from the same source, suffering practically the same fluctuations, thus eliminating the error." I do not know that I correctly understand that. It seems on reference to Fig. 1, that if the current passing through the instrument A–E. and going through the one heavy convolution around the little transformer, were to vary suddenly, that would not necessarily make the current in coil B vary equally, and consequently always balance it, because the current in coil B, as it is drawn here, appears to be taken across the poles of the generator D, C, in other words, in proportion to the voltage of the generator. Whereas the current in the coil A is current that is actually being drawn from the generator. The reason I ask this question is that if I understand the diagram right, this arrangement will not permit you to get increase of current, but only measurement of current at particular values, after which particular values you must adjust by hand the water rheostat H. If this is the case, its usefulness, while still exceedingly great, is limited more to calibration than to indication. I sympathize with Professor Ryan in regard to the costs of connecting up instruments for measuring large currents. It is only within the last few days, in connection with my work, that I had to authorize the expenditure first of a hundred dollars or so for the shunt, and a milli-voltmeter, and then nearly another hundred dollars for heavy copper castings and lugs and conductors and tips and bolts and things, in order to make these other parts useful, and some way to avoid that is very desirable. But from what I read in the paper, I do not understand that Professor Ryan intends his method to be used, for instance, where a set of observations are desired, under a condition of varying current, as in the case of dynamo testing, with the loads continually varying.

DR. SHELDON:—On page 265, in the second paragraph, the statement is made that "Where two direct current carrying coils of similar dimensions are placed side by side and linked with a closed laminated iron core of low reluctance the permeability of this core for alternating magnetic flux will be a maximum when

the ampere turns of the two coils are equal and opposite." I should think that two coils of that character would exactly neutralize each other, and therefore there would be no magneto-motive force. If that were the case, the iron core would be exactly in a neutral condition. Now, if the iron core have the ordinary form of magnetization curve with the instep, the shin, the knee and the thigh, the permeability, which is equal to the flux density divided by the magnetizing force, would be a maximum not when there is a zero-flux, but when the iron is magnetized in either one direction or the other to a point somewhere near the knee of the curve. The indication on the electro-dynamometer, G, would be a maximum when there was an excess of ampere turns in either the large current coil or the low current coil; that is, at the exact neutral magnetic condition of the iron when the two magneto-forces are exactly equal and opposite, it would not give a maximum deflection in the electro-dynamometer.

PROFESSOR RYAN:—If I may answer these questions at this point it will facilitate my keeping them in mind during the discussion. As to the point, first of all, brought up by Mr. Dunn, I should be sorry if the paper were interpreted as though I meant to advocate that this method should be used for any other purpose than merely to calibrate instruments of the milli-voltmeter and shunt type already installed. If one must put those instruments into circuits for the measurement, presumably with laboratory facilities, they have been calibrated with reference to low resistance standards. But the method is intended more particularly for the calibration of switchboard instruments that are very excellent if one simply knows their constants or knows that they are right as to adjustment. It is a zero method, and Mr. Dunn is right in calling your attention to the fact that as such it can have no practical value for any other than calibrating purposes. It is to avoid the trouble that he spoke of, of having to make the expensive and troublesome heavy current connections for checking up instruments, that this method is to be used. Station instruments as now ordinarily made can very well be used for testing purposes, or for the ordinary purposes that come up as duty in the station, if one only knows, after they have been used for some time, what their character is as to adjustment—knows that they are right, or if they are off, how much they are off.

As to the point that Dr. Sheldon has just now brought forward with regard to magnetic action that goes on in the magnetic circuit, the very reason why we have adopted the alternating current test here, or rather permeability to alternating flux test, is in order that the trouble of all sorts that comes from the irregular portion of the B–H curve of iron will be eliminated. We thought of a great many plans by means of which we would not have to resort to the driving commutator and the alternating permeability test that we have finally adopted in that method, and found none so satisfactory as this. On thinking the matter over and remem-

bering the nature of iron on the basis of the B–H curve, you will remember that permeability for reversal under magneto-motive force is a maximum so long as it is being done symmetrically about the axis. Anything that offsets it in regard to the zero line gives you a smaller range of travel for a given alternating effect plus a constant effect than you otherwise would obtain.

Dr. Arthur E. Kennelly:—The paper is interesting, if only for illustrating the modern tendency to turn to alternating currents when we encounter difficulties with direct currents. A short time ago we had so much difficulty in calibrating alternating apparatus that we used to have recourse to direct-current methods. Now the tables seem to have turned, and Professor Ryan goes to alternating currents in order to facilitate direct-current calibration.

The plan, as I understand it, is both interesting and ingenious, and consists in determining when there is zero-flux in a magnetic circuit operated upon by two continuous magneto-motive forces in opposite directions, one being from a single turn, carrying the powerful current to be measured, and the other being from many turns, carrying a small measured current. If I understand the matter correctly, and I have only just seen the paper, the alternating-current theory applies in the manner suggested by Professor Ryan just now, inasmuch as for cyclical alternations their amplitude is greatest, as he says, just at the zero point of flux in the magnetic circuit, although for direct-testing currents the criticism made by Dr. Sheldon would no doubt apply. There is one difficulty that occurs to me, and that is in regard to hysteresis. Suppose the big current through the single turn were applied first; that would magnetize the iron up to a certain extent. Then suppose the small current applied through the many turns. Although the two magneto-motive forces might be equal, and might have zero effect if turned on simultaneously, there might be, under the preceding conditions, a residual magnetism, due to hysteresis, and I suppose that unless that is wiped out by the testing alternating current the permeability would be affected thereby and the results vitiated. I suppose the alternating current must have sufficient magnitude to erase that residual magnetism. I see Professor Ryan indicates that my supposition is right.

It seems to me that the apparatus ought to be very useful for application in power stations and where elaborate apparatus cannot be availed of. But I suppose that Professor Ryan would not recommend this method to supersede, for laboratory testing, the calibration of ordinary apparatus.

Professor Ryan:—Dr. Kennelly is right in interpreting the view, at any rate, that I have with regard to the alternating current equalizing this hysteresis effect. The alternating magneto-motive force, whatever the difference may be, owing to the coming on at different instants of these two sets of direct magneto-motive forces will cause that difference to disappear. We have found it so. We have been very careful to examine that point. That is

one great reason why we had to come to the use of the alternating magneto-motive force. By no other method, though we tried a great many, could we get over these very difficulties that Dr. Kennelly and Dr. Sheldon have spoken of.

I do not at all wish to put the method in competition with the refined method of adjusting an instrument, the Reichsantalt low resistant heavy current standard, and the Clark cell and the potentiometer, or a laboratory pattern of the milli-voltmeter, as made by an eminent maker of electrical instruments—not at all. But you cannot take your laboratory facilities with you into electric light and power stations, while, with these coils, you can consume very little time in applying the calibrating transformer method. I think it is well to remember that the laboratory methods, using the Reichsantalt standard, while splendid in the laboratory, will consume too much time and require one to use expensive connections for their application in the power house.

Mr. C. O. Mailloux:—I understand this method to be a zero method, which, however, differs from most zero methods in so far as the indicating instrument does not indicate zero reading when the zero point is reached, but indicates a maximum reading; that is to say, in this case when the point of zero flux in the core of the special transformer is reached, the galvanometer G gives the largest deflection. I would like to ask Professor Ryan, if this be the case, whether it would not be possible to make the transformer coil *b*, such that instead of having to step down from the coil *a*, it would step up; in other words, use a coil having a very large number of turns of fine wire, and then simply connect the terminal of that coil to an ordinary alternating current voltmeter. It seems to me that if instead of stepping down and getting a very delicate deflection, he were to step up and decrease the action, that he would then be able to get an action sufficiently great to show indications on the ordinary voltmeter such as are made for alternating current, and as the operation is one which is read by reference to the largest deflection, it seems to me that he would be able to get as good accuracy by that means as by the use of the very delicate milli-voltmeter or of the galvanometer G.

Professor Ryan:—In reply to the point brought up by Mr. Mailloux, we adopted this plan for the reason that there is some practical value, I think, in being able to use one of the milli-voltmeters of the same type that is used for ammeters, that one applies this method ordinarily to, to calibrate. That is, however, but one reason, and rather an unimportant one, I think. The most important factor determining this way of applying the balance test, or alternating permeability balance test, has been that we must not introduce too much activity of an alternating character there, or by mutual induction there will be interference. The method will not have the same integrity that it has with the smaller alternating activity of flux densities and periodicity that

you can so easily make use of by applying the direct current instrument to test for balance through the two-part commutator.

MR. HANCHETT:—Would it be possible to open the magnetic circuit, and introduce therein a D'Arsonval coil neutralizing any residual magnetism, if such occurs, by means of an alternating current coil wound on the same core? A D'Arsonval coil, if a voltage were applied to it, would deflect if there were any flux, and would remain at zero if there were zero flux.

PROFESSOR RYAN:—We began with those models, and had to come to this arrangement. We had that one and a number of other models modified a good bit from the one that has just been brought up, and met with no success. I do not mean to say that final success could not be obtained that way, but we were not able to make progress, and further discussion of the matter as to why not, would involve a number of wee little things that made our experience with the method in attempting to use those models rather a discouraging one for the time being.

MR. TOWNSEND WOLCOTT:—Mr. President, I would like to ask Professor Ryan one question in regard to the maximum. How rapidly does the permeability vary in the neighborhood of the maximum value; in other words, how accurately can the maximum point be determined? Most maxima occur where the differential coefficient of the function is zero, and the rate of change is usually very small in the immediate neighborhood of a maximum, on both sides, and the maximum is consequently difficult to locate accurately by measurement.

PROFESSOR RYAN:—In reply to that matter, I may state that you will find, any of you, in trying the method, that the maximum is very crisply defined. I mean by that, however, that it is defined within such narrow limits in the balancing coil, that the errors of determination are within those that we care anything about for engineering purposes, namely, a quarter of one per cent.

THE PRESIDENT:—I would like to ask Professor Ryan if he found that it made any difference whether the current to be measured is brought from a lower value up to the desired reading, or is brought down to that reading; that is, is the effect of a previous increase or decrease in the main current noticeable? In other words, does the alternating current entirely wipe out a residual magnetic effect that might have been induced by an increasing as distinguished from a decreasing current?

PROFESSOR RYAN:—We have found that it does, with the proportions that are advised in this paper. You are not able to distinguish as to the value obtained, whether you come to the balance by bringing the balancing current there from a lower value to a higher value, and thus to the balancing point, or by first going up and then dropping down to it; the same values are obtained either way.

THE PRESIDENT:—That is, because you use an alternating current in the testing apparatus?

PROFESSOR RYAN:—Yes.

THE PRESIDENT:—It would probably not be the case if the arrangement just suggested by Mr. Hanchett was used, because there would probably be an after effect of the current.

PROFESSOR RYAN:—There would be that, and the insertion of a gap in the core induces many troubles.

THE PRESIDENT:—Do you not have to be very careful about the magnetic leakage? In other words, do not the windings of the two direct currents have to be in very close proximity to each other and absolutely symmetrical with each other? Because it seems to me that if there is magnetic leakage between them, due to those strongly magnetizing currents, it would produce quite an error in the reading.

PROFESSOR RYAN:—The matter just referred to we went into quite carefully, and find that by adopting the type of transformer, as stated in the paper, and which I illustrated by means of a lantern slide, and disposing of it in the manner there shown, one is not then called on to incur any risk in this respect whatsoever, according to our experience. In other words, the disposition of the balancing coil and its core, with reference to the conductor carrying the heavy current, must be such as to produce a local field on the part of the one coil through the core that is not pronouncedly different from the local field that is produced by the other conductor or coil. Now for the core that passes around the conductor, with the balancing coil mounted upon it, going entirely around that core, and giving to the core and the balancing coil thereon wound, an outline that corresponds to the conductor cross-section, one incurs no risk of error in this respect whatsoever, according to our studies. The case, for example, that we had on the screen, that same coil which we there used for calibrating the 4,000-ampere ammeter, we used likewise on a 750-ampere circuit, where the conductor carrying the current was very much smaller. We placed that at the center of the rectangular core. Immediately on one side was the equalizer blade of the same switch carrying current. That, however, would not produce error, because any stray field that it sets up is in common with the magneto-motive force action of the balancing coil and the main conductor that is carrying the heavy current that passes through the balancing coil. With that design of transformer that is here advised, whatever leakage defects there are, they occur in such a respect that there is no interference with the indication of the true balance. The balancing coil does not present in effect more ampere turns than the actual number that it possesses, nor does it present less.

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There being no further discussion, a paper by Professor F. W. Brady on "Electricity in Mountain Mines" was read by Dr. Sheldon for the author.

[See p. 281, April issue.]

## Discussion.

Dr. N. S. Keith:—Mr. President, this paper is almost exactly familiar to me. It rehearses many of the trials which I have experienced in the mountains of California and of Colorado and in other countries. I have no criticism to make of it. I know gentlemen here, from their smiles, who work in cities, above ground, and underground only when in dry locations; where they have railroads, wagons, horses, their men who have had experience in handling the goods, cannot appreciate the difficulties which the engineer, especially the electrical mountain engineer, meets everywhere he goes. He goes into the highest mountains, 15,000 feet above the sea; he goes into the lowest depths, two or three thousand feet below the surface; he has water dripping upon him, which runs continuously in the locations where he is obliged to put such delicate apparatus, such we used to consider them, as the electric motor and the generator. I need not enlarge upon these facts, because they will become familiar to some of you who will be obliged, in carrying out the details of your profession, to go into such localities. There the electrical engineer will be called upon to exercise his common sense, his adaptability to the conditions over which he has no control whatever, but where he has to confine himself to circumstances which he cannot alter. I can add one instance which shows a variation in the methods of conveying electrical apparatus to the mine. There are three mentioned in this paper, one of which is by a wagon road, another is by mule trail, another by an aerial tramway. I have a fourth one: A plant which I erected in the Alps, in the mountains of northern Italy, in 1896. The last five kilometres of the route from England to the mine at Pestarina, at the foot of Monta Rosa, was only approachable by a trail for that distance. There were but two mules in the whole country, and they were used only in the summer time to carry tourists who desired to climb the mountains and go to the glacier at the foot of Monta Rosa, and some of them have crossed the Swiss border into Switzerland. Those mules could not be used for the carrying of freight; but there was a regular transportation line which consisted in using the backs of men and women. The heaviest piece of apparatus which I took in there weighed 2,000 pounds; that was an armature. It had to be constructed at the shops in England and taken in that shape. The field of the generator was made of laminated iron and was put together, and the coils slipped upon the legs of the magnet in place. The armature was carried by sixteen men under a peculiar arrangement of poles, so they could all carry at the same time. It was taken over five kilometres (3½ miles) in that way. There was another heavy piece of machinery, a large turbine, made in Switzerland, to be taken in that way. I have some photographs of the methods of transportation which were used in carrying that apparatus into the

mountains. The power was to be transmitted for a distance of three miles, or so, down into the mine for the operation of pumps, pumping a direct column of 900 feet in height. One of the difficulties which should belong strictly to the mechanical engineer or the mining engineer, but which had to be met by the electrical engineer, was the one of properly regulating the pressure of the pump and the column of water which had to be raised. These were triple plunger pumps. The column of water is not a constantly flowing one; it comes partially to rest between the different movements of the plunger. Under such extraordinary pressures, the air that is in the water, and which is used ordinarily in the air chambers, so as to equalize these extraordinary variations in pressure, is absorbed by the water and we had to provide a pump by which we could pump air into the air chambers of the pump. In that matter I had to meet the ordinary everyday Cornish mining engineer, with his conceited ignorance. He had always operated a Cornish pump which lifted water a hundred feet, emptied into a vessel, and from that vessel lifted another hundred feet, and so on until it reached the surface, 900 feet above the source of water; he did not at all understand an air cylinder attached to a pump; he said it simply increased the amount of power needed. After a great deal of trouble I was enabled to put in the proper air cylinders. But when I left the country and returned to England, he removed those air chambers, with the result that the pump was broken, and at the same time some of the pipes were burst. I only mention this to show some of the difficulties which the electrical mining engineer has to encounter, and as an addition to the items of this paper.

MR. C. O. MAILLOUX:—I am not an old pioneer like Dr. Keith; I am only what is usually called, out West, a "tenderfoot;" yet I wish to state that even we Eastern tender-feet sometimes have occasion to visit the wild and wooly West and to have experiences. These experiences are usually valuable. I was visiting a large water power electric station in Southern California a couple of years ago, and after seeing the inside, I went outside to inspect the outer portion of the station, and incidentally to take a photograph of it. My guide, who was one of the station attendants, was very kind and freely explained everything to me, but he had forgotten to explain one important feature of the locality, which soon proved to be the most interesting. After examining the tail-race and noticing the features of interest in it, I tried to get away to a little greater distance from the building so that I could include a greater portion of the building in the picture when I saw my friend, who was perhaps ten feet away from me startle somewhat unexpectedly. I asked him what was the matter. He said: "Oh, it is nothing; it is only a rattle-snake." You can imagine my feelings. I did not have much interest in photography for the next few minutes. He quickly killed the rattle-snake, while I quickly got into the carriage and went back to the city.

I have also had occasion to camp out twenty-five or thirty miles away from the nearest city or town with a party of civil, hydraulic and electrical engineers, investigating water-power sites, and I have heard the cayote and the mountain lion disport themselves during the night, and heard the bat flit about and make things interesting, together with innumerable bugs, mosquitoes, etc. These experiences in distant climes have impressed on my mind two things—first, the difficulties of transportation, which are very strongly put but not at all exaggerated in the paper, and, secondly, the necessity on the part of the electrical engineer designing an installation for use in those localities, of attending to what I have learned to designate the "fool-proof" features of the installation. With reference to the first point, I may cite an installation which I have in hand in Arizona, where the item of freight and cartage is fully 20 per cent. of the cost of the machinery, although there is little if any mountain climbing to be done, the cartage being mostly over relatively level desert lands. As to the second point, the engineer should take into consideration the character of the talent that is likely to be called upon to take charge of the installation after it is finished, and the matter assumes sometimes very important proportions, especially when the plant is one employing higher potentials for transmission to long distances, and where several generators are to be used together, especially, as is the case in lower California, where several stations located at different points all connect with the same transmission line. The manipulations incidental to the synchronizing of machines, coupling them electrically together, the regulation of the water-wheels and the regulation of the electrical machines, etc., are at best, operations which require a certain amount of intelligence; but when these have to be attended to by people whose general education is none too great, and whose specific education, electrical and technical, is a vanishing quantity, one realizes the importance of having the outfit so designed that it will require the least amount of thought and discretion on the part of the attendant. In other words, it is absolutely necessary that the outfit should be made "fool-proof," so that not only the attendant may not be able to do any damage to the installation, but even that he may not be able to do any damage to himself, for in many cases he might be able to do both. In discussing this matter with the engineers of a large company in connection with the Arizona installation aforesaid, I mentioned to him that the station equipment would likely be in charge or in care of a type of individual, who in Arizona, they call "zanjero," a Spanish term used in irrigated districts of the Southwest to designate the man who regulates the flow of water—a gateman, or dyke-man, so to speak; and he at once agreed that if the man's name is "spelled that way," it is certainly necessary to make the thing as simple and as fool-proof as possible.

THE SECRETARY:—There appear to me still other and different lessons to be taught by a paper of this kind. In the first place, it appears to me that the difficulties that the writer speaks of at the outset are due to lack of engineering, either at one end or the other, or at both, and evidences of the negotiations being carried on by commercial men rather than engineers. One of the first things that an engineer should know is the location of the plant that he is about to install, and certainly if he could have a chance to see the views that are to be shown this evening he would obtain an idea of what it is necessary to provide against. It is the tendency of these pioneers and veterans to dwell upon the hardships that a young man will encounter in such places. I was once a tender-foot myself, and I know something about electricity and something about mountains and a very little about mines, and I have had some experience with mules. But my idea is that any of these young men who are brought up here in the city and graduate at colleges, if they are not equal to any of these emergencies that arise in cases of this kind, have mistaken their calling and should take up something like an Episcopal rectorship. As a young man with enthusiasm for his profession meets those difficulties he will grapple them, and his ability will grow as the difficulties increase. I have never yet seen a young man of that kind who would simply lie down and not carry a project through. It is all very well for Dr. Keith and Mr. Mailloux to stand here and tell what you have got to run up against, and it is very good advice, but I have seen a good many young men without experience, and there were in our party in British Columbia several of this class who had never handled an axe or never seen or certainly never packed a mule and never pulled an oar, who held their own against the half-breeds and woodsmen, and would tackle hardships that the others would not endure, certainly not without grumbling. This matter was brought to my mind the other day by a letter which was written to my nephew, who had applied for a position in the signaling department of a certain railroad. I will not undertake to read this through, but I want to give you an idea that it is important to these young men. Now, this young man is a son of my brother, the late Franklin Leonard Pope, and is of as good stuff as his father, and he cannot be disconcerted by any of these assertions about his not being equal to the emergency. The letter says: "Yours of the 17th at hand. My experience with the average college man is that when put on hard work of a physical nature he is a 'quitter,' not necessarily because he is naturally lazy, but because the manual labor is too hard for him. This is unfortunate, but nevertheless true." Well, all I have got to say about those quitters is that they have mistaken their calling. What an engineer wants to know is whether there is money enough to carry out the plans. There is another thing that he wants to know, and that is whether there has ever been a man in that mine. If there has ever been a man there he will undertake to

put a plant there. He might not know before he went just how he was going to do it, but if he was an engineer and was given ample means to provide all possible facilities he would install the plant, and before he got through with it, it would work.

THE PRESIDENT:—Speaking about getting over difficulties in mines reminds me of a case that you may have heard of, in which a mine which descended into the side of a hill had water in it, which had to be pumped out. There was no water power anywhere in the neighborhood with which to do it, so a pipe was laid from the bottom of the mine up to its mouth and thence down the side of the hill to a point below the level of the water in the mine; a water power plant was placed at the lower end, which by means of electrical transmission operated a pump in the mine which pumped the water into that pipe. Thus the water in the mine furnished the power itself, the whole combination acting like a siphon would for less heights. It shows the flexibility of electrical transmission.

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Lantern slides were then shown, giving the characteristic features of the country in which the described mines are located.

[Adjourned.]

# AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 21, 1901.

The 18th Annual Meeting was held this date and was called to order by President Hering, at 8:10 P.M., who appointed Messrs. Edward Caldwell and Douglas Burnett as Tellers, and William Maver, Jr. and George A. Hamilton as Proxy Committee.

THE SECRETARY:—At a meeting of the Executive Committee this afternoon, the following Associate Members were elected.

| Name | Address | Endorsed by |
|---|---|---|
| BALL, HENRY PRICE | Electrical Engineer General Incandescent Arc Light Co., 572 First Av., New York, residence, 66 So. Parsons Ave., Flushing, L.I. | Luther Stieringer. Martin J. Insull. Samuel Insull. |
| BENTLEY, EDWARD M. | Patent Attorney and Expert, Temple Court, New York City. | C. P. Steinmetz. Albert G. Davis. Ernst J. Berg. |
| BLACK, ROBERT GIVEN | Supt. The Chambly Mfg. Co., Richelieu Village, P. Q. | R. B. Owens. R. D. Mershon. R. A. Ross. |
| BOLLES, FRANK G. | Manager Advance Dept., Bullock Elec. Mfg. Co., Norwood, Ohio. | E. G. Bernard. Wm. J. Hammer. W. D. Weaver. |
| BRADY, NICHOLAS F. | Treasurer, the Edison Illg. Co., 57 Duane St., New York City. | J. W. Lieb, Jr. C. W. Rice. W. S. Barstow. |
| BYRNES, EUGENE A. | Principal Examiner Electro-Chemistry and Metallurgy, U. S. Patent Office, Washington, D. C. | E. A. Sperry. F. L. Freeman. E. G. Acheson. |
| CUNNINGHAM, RICHARD H. | Demonstrator of Physiology, Columbia University, New York City. | E. G. Willyoung. F. W. Roller. T. C. Martin. |
| DASSORI, FREDERICK HUMBERT | Student, Polytechnic Institute, 250 Union St., Brooklyn, N. Y. | Samuel Sheldon. Ralph W. Pope. Wm. J. Hammer. |

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| DONALDSON, WM. W. | Electrical Engineer, The Gould Storage Battery Co., 25 W. 33d Street, New York City. | Frank B. Rae.<br>C. T. Hutchinson<br>T. C. Martin. |
| DRESSER, CHARLES A. | Superintendent, Kohler Bros., 1808 Fisher Building, Chicago, Ill. | C. G. Armstrong.<br>William Goltz.<br>F. B. Badt. |
| DROHAN, T. E. | Superintendent of Shops, Northern Elec. Mfg. Co. Madison, Wis | A. P. Kennedy.<br>D. F. Stakes.<br>O. S. Lyford, Jr. |
| EDDY, HORACE T. | Instructor of Electrical Engineering, Union College, Schenectady, N. Y. | A. L. Rohrer.<br>E. M. Hewlett.<br>C. P. Steinmetz. |
| ELLIOTT, ELMER G. | With Guggenheim Smelting Co., Perth Amboy, N. J. | Wm. A. Anthony<br>W. G. Whitmore.<br>J. C. Bennett. |
| FRASER, JAMES WM. | Demonstrator in Electrical Engineering, McGill University, Montreal. | R. B. Owens.<br>L. A. Herdt.<br>E. M. Archibald. |
| HAWES, H. D. | Engineer with General Electric Co., Schenectady, N. Y. | W. I. Slichter.<br>Ernst Berg.<br>A. H. Armstrong. |
| HENRY, IRA WALTON | Cable Engineer The Safety Cable Co., 229 W. 28th Street, New York City. | R. W. Pope.<br>A. E. Kennelly.<br>Wm. Maver, Jr. |
| HERRICK, ALBERT B. | Consulting Electrical Engineer, 120 Liberty Street, N.Y., residence, Ridgewood, N. J. | H. W Blake.<br>W. D. Weaver.<br>T. C. Martin. |
| HESKETH, JOHN | Electrical Engineer, Queensland Government Post and Telegraph Dept., Brisbane, Queensland | J. S. Fitzmaurice.<br>W.G.T.Goodman.<br>A. J. Hanson. |
| HEWITT, PETER COOPER | 11 Lexington Ave., New York City. | G. H. Stockbridge<br>C. A. Terry.<br>T. C. Martin. |
| HOLTZER, CHAS. WM. | President Holtzer - Cabot Elec. Co., Brookline, Mass. | E. P. Thompson.<br>Wm. Stanley.<br>G. W. Blodgett. |
| JENKS, ARTHUR PERKINS | General Electric Co., 44 Broad St., New York City. | A. L. Rohrer.<br>H. G. Reist.<br>T. C. Martin. |
| KEBLER JOHN LEONARD | Vice - President Ward - Leonard Elec. Co., 606 W. 114th Street, New York City. | H. Laws Webb.<br>H. W. Leonard.<br>T. C. Martin. |
| MARSH, CHAS. J. | General Manager, Eastern and Northeastern Sales Depts, Standard Underground Cable Co., 58 Liberty St., New York City. | J. W. Lieb, Jr.<br>E. A. Leslie.<br>G. L. Wiley. |
| MERRILL, JOSEPH F. | Professor of Physics and Electrical Engineering, University of Utah, Salt Lake City, Utah. | B. B. Brackett.<br>H. S. Carhart.<br>C.T.Hutchinson. |
| MINTNER, LOUIS | Engineer Switchboard Dept., General Incandescent Arc Light Co., 572 First Av., N.Y. | Luther Stieringer.<br>Martin J. Insull.<br>Samuel Insull. |
| MURRAY THOS. E. | General Manager N. Y. Gas and E. L. H. & P. Co., 55 Duane Street, New York City. | J. W. Lieb, Jr.<br>Calvin W. Rice.<br>W. S. Barstow. |
| POIRIER, ALFRED E. | Manager N. Y. & N. J. Tel. Co., Jersey City, N. J., residence, 29 W. 21st St., N. Y. City. | R. W. Pope.<br>G. A. Hamilton.<br>F. M Pedersen. |

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| POWELL, EDWIN BURNLEY | Meter Tester, Edison Electric Illuminating Co., 55 Duane St., New York City. | Calvin W. Rice.<br>H. A. Lardner.<br>M. B. Waterman. |
| REID, WILLIAM | Switchboard Engineer, N. W. Telephone Exchange Co., Tel. Bldg., Minneapolis, Minn. | G. D. Shepardson<br>C. L. Pillsbury.<br>J. C. Kelsey. |
| RICE, MARTIN P. | Chief of Publication Bureau, General Electric Co., Schenectady, N. Y. | C. P. Steinmetz.<br>Eskil Berg.<br>E. W. Rice, Jr. |
| ROGERS, NELSON | Electrician, with Peter Cooper Hewitt, Madison Square Garden Tower, New York City, residence, Mt. Vernon, N. Y. | Chas. A. Terry.<br>A. J. Wurts.<br>F. A. La Roche. |
| RYDER, M. P. | Supt. of Bronx Dist., N. Y. Gas and Electric L. H. & P. Co., 699 Union Ave., N. Y. City. | E. A. Leslie.<br>Calvin W. Rice.<br>W. F. Wells. |
| SAGE FREDERICK BRITTAN | Partner, F. B. Sage & Bro., 123 Liberty St., N. Y. City. | Townsend Wolcott<br>G. T. Hanchett.<br>C. E. Whitney. |
| SALTER, THOS. FITCH | Designer and Inspector of Drawings, Western Elec. Co., residence, 11 W. 18th St., N. Y. | G. F. Atwood.<br>O A. Bell.<br>F. A. Muschenheim |
| SPELLMIRE, WALTER B. | District Engineer, Bullock Elec. Mfg. Co., 220 Broadway, New York City. | Thos. French, Jr.<br>R. T. Lozier.<br>W. M. Venable. |
| SPENCER, CHAS. J. | Electrical Engineer with N.Y.C. & H. R R. R. Engineering Dept., Room 512 Grand Central Sta., New York City. | C. P. Steinmetz.<br>J. H. Vail<br>S. L. G. Knox. |
| TAYLOR, ALBERT | Manager New York Office, Electric Storage Battery Co., 100 Broadway. New York City. | Herbert Lloyd.<br>Chas. Blizard.<br>J. B. Entz. |
| WALKER, FRANK WILKES | Student in Electrical Engineering, McGill University, 26 Summerhill Ave., Montreal, P. Q. | R. B. Owens.<br>R. W. Pope.<br>L. A. Herdt. |
| WENGER, EDGAR I. | Graduate-Student in Electrical Engineering, McGill University, Montreal, residence, Ayton, Ontario. | R. T. Lozier.<br>R. M. Wilson.<br>R. B. Owens. |
| WHITNEY, WILLIS R. | Asst. Prof. Theoretical Chemistry, in charge of Electro-Chemical Research Laboratory, General Electric Co., Schenectady, N. Y. | C. P. Steinmetz.<br>A. G Davis<br>E. W. Rice, Jr. |

Total, 40.

THE PRESIDENT:—During the past year, there have been a number of new departures in the affairs of the INSTITUTE. Among the most important if not the most important, is one which I have the great pleasure of announcing to you to-night. One of our oldest members has recently purchased and presented to the INSTITUTE the very valuable library of Latimer Clark in London, which is the finest of all existing electrical libraries of the earlier works. I will ask the Secretary to read his letter which was sent to Council to-day, and which was followed by the formal acceptance of the library by Council in behalf of the INSTITUTE.

The Secretary read the following letter.

To the Council and Members of the
American Institute of Electrical Engineers.

It is my privilege to be able to announce the completion of negotiations by which I have become the possessor of the very remarkable collection of electrical books of the late Mr. Latimer Clark of London.

My object in securing this collection was to present the books to our Institute and make it the custodian of the most complete electrical library in the world, as well as to stimulate such interest that the Institute may in time own a permanent home in New York.

The assurances received from those who have co-operated with me in this undertaking, that the collection is very complete and includes practically every known publication in the English language previous to 1886, on Magnetism, Electricity, Galvanism, the Lodestone, Mariner's Compass, etc., have been more than verified by my own examination of the books since their arrival in this country. There are among its 7,000 titles many books which are not to be found in either of the famous libraries with which it has been compared, and I find that there are even some of the very earliest examples of printing.

I have always been a strong believer in the principle that every professional man is under obligation to contribute in some way to the welfare of the profession in which he is engaged, and in obedience to this idea I now desire to present this library to you complete, reserving to myself only the photographs, autographs and such duplicate books as I may add to my own collection without detracting from the completeness of the library.

As an early contributor to the Institute and one of the original members of its Building Committee I am interested in securing for it permanent headquarters and adding to its importance, dignity and strength. It is my desire that the Institute accept the library and through its Library Committee and a suitable Librarian administer it in such a way as to make it generally useful, and I hope that the possession of these books will add to the Institute's prestige.

I am inclined not to suggest rules for the management of the library, believing that those who are in charge from time to time are in the best position to know what is desirable; but in order to fix its general character, and secure its permanence, I condition the gift upon the acceptance by the Institute of the following provisions:

First.—The library to be kept insured against loss by fire as fully as it may be practicable to determine its value, and an annual appropriation of $1500 to be provided for its maintenance.

Second.—A complete catalogue raisonné to be published in the name of the Institute reciting the conditions of gift and explaining the features of interest of each book for the convenience and information of members. This catalogue to be prepared at once and a bound copy of it to be placed in the hands of each member of the Institute.

Third.—The library to be in charge and control of a Library Board or Committee made up of members of the Institute and not more than one quarter of the whole number of members of this Committee to be allied with any one commercial or other interest.

Fourth.—The library to remain in New York City and to be a reference library, free to all, including non-members and available for consultation at least three days in the week and some evenings and some Sundays, as soon as the Institute is in permanent quarters.

FIFTH.—Rare books, that is, books which it is practically impossible to replace, to be exhibited under glass with suitable explanatory cards and to be subject to closer examination only at the library and upon suitable introduction of the visitor to the Library Committee or their representative, the Librarian, and under such other precautions as will positively assure the preservation and safety of the books.

And further, it is my earnest desire that the INSTITUTE shall within five years, raise a sufficient fund by subscription, and provide itself with a permanent home for its meetings and library, and that this home shall be centrally located, reasonably safe from fire and not heavily mortgaged.

In case of the failure of the INSTITUTE to comply with the substance or spirit of these conditions, or with the desire expressed above for a permanent home, the library shall revert to me or my heirs or assigns.

Having in view the sole purpose of encouraging the INSTITUTE to attain the position which I feel sure all of its members desire, I have sought to name conditions easily within its reach.

SCHUYLER SKAATS WHEELER.

AMPERE, N. J., May 17th, 1901.

THE PRESIDENT:—The library has already been described, and you are therefore probably familiar with the fact that it is the finest library of its kind in the world. Not only is this a very valuable gift from Dr. Wheeler, which is in itself very valuable, but more than that it is the beginning of an effort to get for us a permanent home, a building where we can not only have our library, but our meeting room, a building which we can call our own. One of the purposes of Dr. Wheeler, as you have seen from his letter, is to lead to the accomplishment of that very desirable object. With such a start as he has given us, we hope, in the course of a few years, to accomplish this much desired result. The gift of Dr. Wheeler has already borne fruit in this way, that your officers and committees have recently visited Mr. Carnegie and have secured from him a very generous offer to give us for the maintenance of our library a sum of money equivalent to its cost. This has not been announced before, because we could not accept the generous offer of Mr. Carnegie until we had received the gift of Dr. Wheeler. Dr. Wheeler's gift having been presented to-day, Mr. Carnegie's gift can also be considered as having been presented to us to-day. [Applause.]

MR. C. O. MAILLOUX:—Although it is likely that the Council and the Library Committee will, at some future time, give fitting expression to the gratitude of the INSTITUTE in a proper manner, yet I think that the members present ought to put on record their own appreciation of these generous gifts by a vote of thanks. Dr. Wheeler is entitled to our gratitude, not only for the intrinsic value of the unique collection of books which he has just donated to the INSTITUTE, some of them of priceless worth, but also because he has set a beautiful example of gener-

osity, which it is hoped may act as a precedent and incentive for others who like him are so fortunately situated as to be able to spare some of this world's goods to help a worthy cause.

I wish to commend particularly the altruistic tone of Dr. Wheeler's letter to the admiration, and for the emulation of the members. He has, on many occasions in the past, shown proof of his public spirit and zeal in studying and fostering the welfare of the electrical engineering profession, and of this INSTITUTE. In this gift he again illustrates and fortifies precept by example, and lives up to his convictions in a manner most acceptable, and, at the same time, highly impressive and edifying to this INSTITUTE.

I do wish therefore to move, and I ask the members to join me in a vote of thanks to Dr. Wheeler for his generous gift of the Latimer Clark library to this INSTITUTE.

[The motion was seconded and unanimously carried.]

MR. CHARLES P. STEINMETZ:—I also move a vote of thanks to Mr. Andrew Carnegie for his generous gift, which enables us to properly establish and maintain this library which we have received as a present from Dr. Wheeler. [Adopted.]

The Secretary then read the following telegram:

"International Hotel, Niagara Falls, N. Y.,
"May 21, 1901.

"Carl Hering:

"President AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, 12 West 31st Street, New York.

"Members of the INSTITUTE OF ELECTRICAL ENGINEERS attending the Convention of the National Electric Light Association send greetings and congratulations upon the gift of the Latimer Clark library by Dr. Wheeler. (Signed): T. C. Martin, Calvin W. Rice, Chas. F. Scott, W. E. Goldsborough, H. H. Humphrey, A. J. Wurts, D. R. Lovejoy, E. H. Mullin, Joseph Sachs, E. F. Peck, J. I. Ayer, Wm. Brophy, W. B. Jackson, H. A. Lardner, Paul M. Lincoln, J. B Cahoon, and many others."

The Secretary read the following reports of the Council, and of the Treasurer, which were accepted and ordered filed.

## AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF COUNCIL FOR THE FISCAL YEAR ENDING APRIL 30, 1901.

The Council submits herewith, for the information of the membership at large, a report of its work during the past year, as well as the financial standing of the INSTITUTE.

Two meetings of Council and nine meetings of the Executive Committee have been held during the year.

The Committee on a National Standardizing Bureau continued its work during the year and up to the date when the bill for the establishment of this bureau passed in Congress. Not only was a large amount of correspondence carried on by this committee in furtherance of the bill, but members of it visited Washington and appeared in its behalf before the Congressional Committee.

The binding of the periodicals which have accumulated during the past thirteen years and the shelving of the same has been finished as far as possible during the year. Some of the files are incomplete, but are being filled up through the liberality of various members, and the collection is already of considerable value. To this will soon be added the magnificent Latimer Clark Library purchased for the INSTITUTE and presented by Dr. Schuyler Skaats Wheeler; also complete sets of "Comptes Rendus de L'Academie des Sciences," presented by C. O. Mailloux, and of the "Proceedings of the Royal Society of London," by Edward Caldwell. Mr. Andrew Carnegie has very generously offered to duplicate the amount paid by Dr. Wheeler for the Latimer Clark Library, which sum will be available for completing and cataloguing the collection. F. P. Fish, Esq., has also kindly donated $100 toward a Library of Patents. The INSTITUTE will therefore soon possess the most complete electrical library in the world. It has been necessary to rent another room in the Havemeyer Building for the present accommodation of about 10,000 volumes.

The work of the Committee on Revision of the Constitution has been continued, resulting in a practically new instrument, which was approved by Council April 26, 1901, and notice given at the INSTITUTE meeting on that date that it would be brought up for consideration at the annual meeting May 21, 1901. In accordance with a vote of the INSTITUTE the proposed Constitution was printed and appeared in the April issue of the TRANSACTIONS.

For the convenience of members residing at a distance from New York City, the date of meetings was changed from the fourth Wednesday to the fourth Friday of each month. Several members, especially those connected with colleges, have expressed their appreciation of that change.

Pursuant to the action of Council last year, arrangements were entered into for a joint meeting with the Institution of Electrical Engineers of Great Britain, which was held at Paris, August 16, 1900, in the National Pavilion of the United States on the Exposition grounds. The discussion at this meeting and also a report of the delegation to the International Electrical Congress which followed have been printed in the TRANSACTIONS. Resolutions of acknowledgment and thanks to the Institution of Electrical Engineers of Great Britain for the many courtesies extended to our members were adopted by Council, and under direction of a special committee an

engrossed copy of the same has been executed and forwarded to that society.

It was decided to hold the next general meeting of the INSTITUTE at Buffalo, and a special committee was appointed to prepare a programme. A preliminary schedule has been printed and 4,250 copies sent to European electrical engineers, together with a circular letter inviting them to attend this meeting. The Institution of Electrical Engineers, being practically committed to a trip into Germany this season, could not officially accept our invitation to visit America this year, but as the Buffalo meeting occurs two months later it is hoped that many members may find it convenient to attend.

Continuing the practice begun last year, the Executive Committee, on February 28, 1901, authorized the purchase of $2,000 in Government bonds, out of which a sufficient amount has been placed to the credit of the Compounded Membership Fund to cover all payments made for life membership up to the date of this meeting. This purchase makes a total of $7,000 in Government bonds now owned by the INSTITUTE.

The 149th Meeting of the INSTITUTE was organized as a dinner on January 9, 1901, and was held at "The Arena," on 31st Street. About 100 members and guests were present, and there was a topical discussion on "Electricity in the Last Century and in This." The event was considered a success and greatly enjoyed by all.

On February 8 the Committee on Papers and Meetings outlined a programme for the first Conversazione held by the INSTITUTE. Eleven regular and special meetings of the committee were devoted to this work between February 8 and April 10. The suggestions offered were approved by the Executive Committee. The interest aroused by this Conversazione and the attendance (about 1,000) surpassed all expectations of the committee. It resulted in the acquisition of many new candidates for membership and renewed enthusiasm on the part of officers and members. The thanks of the INSTITUTE are due to Columbia University and the exhibitors for their hearty co-operation with the Committee on Papers and Meetings; also to the members of this committee for their faithful and arduous labors.

There have been held during the year one general meeting at Philadelphia and Paris, the annual business meeting and eight monthly meetings at New York City.

The Board of Examiners has held ten meetings during the year, at which fifty-five applications for transfer have been considered. Of this number thirty-four were recommended to Council for transfer, seventeen held over for additional information and four disapproved.

The total membership at the close of last year's report was 1,183, classified as follows:

| | |
|---|---|
| Honorary Members | 2 |
| Members | 374 |
| Associate Members | 807 |
| Total | 1,183 |
| Associate Members elected May 1, 1900, to April 30, 1901 | 151 |
| Associate Members elected the previous year and since qualified | 20 |
| Total | 1,354 |

Resignations have been received and accepted during the year from the following members and associates who were in good standing:

*Members*—J. W. Lattig, A. Floyd Delafield, Victor M. Berthold, Thomas R Taltavall.

*Associate Members*—Cleveland Abbe, George H. Blaxter, Walter A. Childs, R. K. Dana, James W. Gladstone, T. T. P. Luquer, Charles K. Munns, Henry A. Rowland, A. A. Serva, Alex. Vosmaer, E. R. Keller, J. P. Labouisse, W. E. Lindsay, A. J. Wood, H. E. Dey, J. P. Hall.

| | |
|---|---|
| Total Resignations | 20 |

There have been the following deaths during the year:

MEMBERS:

GEORGE W. GARDANIER, GILBERT WILKES,
ISAIAH H. FARNHAM, ELISHA GRAY.

ASSOCIATE MEMBERS:

JOHN E. HUDSON. JOSEPH CLEMENT,
W. M. T. WEISE.

| | |
|---|---|
| Total Deaths | 7 |
| Dropped as delinquent | 46 |
| Elected, but not yet qualified | 21 |
| Total | 94 |

Leaving a total membership of 1,260 on May 1, 1901 (a net gain of 77, the net gain for the previous year being 45), classified as follows:

| | |
|---|---|
| Honorary Members | 2 |
| Members | 387 |
| Associate Members | 871 |
| Total | 1,260 |

A list of associate members elected during the year accompanies this report, and the names appear in the printed TRANSACTIONS.

The reports of the Secretary and of the Treasurer show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of receipts and disbursements during the entire year:

## SECRETARY'S BALANCE SHEET.

FOR THE FISCAL YEAR ENDING APRIL 30, 1901.

| *Dr.* | | *Cr.* | |
|---|---|---|---|
| Balance from previous year | $256 48 | By Cash to Treasurer | $13,622 36 |
| Receipts for the year | 13,617 39 | Balance to next year | 251 51 |
| | $13,873 87 | | $13,873 87 |

## ITEMIZED STATEMENT OF RECEIPTS AND DISBURSEMENTS OF THE INSTITUTE.

### For Fiscal Year Ending April 30, 1901.

### General Account.

| *Receipts.* | | *Disbursements:* | |
|---|---|---|---|
| Treasurer's Balance from previous year | $2,205 08 | Revenue Tax | $12 35 |
| Secretary's Balance from previous year | 236 48 | Bank Exchange | 8 99 |
| Entrance Fees | 745 00 | Chicago Meetings | 30 06 |
| Life Membership Fees (F. A. Saylor, J. D. E. Duncan, W. E. Chappell, Samuel Sheldon, W. J. Hammer) | 500 00 | Library | 697 55 |
| Past Dues | 615 88 | Ice | 26 09 |
| Current Dues | 9,623 62 | Laundry | 8 25 |
| Advance Dues | 114 38 | Office Expenses | 37 33 |
| Electrotypes Sold | 60 79 | " Fixtures | 3 70 |
| Transactions Sold | 790 61 | Express | 196 79 |
| " Subscriptions | 351 90 | Telegrams | 11 89 |
| Advertising | 55 00 | Stenography and Typewriting | 978 90 |
| Received for Special Binding | 38 06 | Stationery and Miscellaneous Printing | 501 91 |
| " " Congress Books | 4 20 | Postage | 589 90 |
| " " Inter't on U.S. Bonds | 150 00 | Messenger Service | 20 74 |
| " from F. P. Fish, Library Donation | 100 00 | Salary Account | 2,541 64 |
| Received for Badges | 232 00 | Meeting Expenses | 192 10 |
| " " Certificates | 30 75 | Rent—Offices and Hall | 1,191 68 |
| " " Conversazione Tickets | 905 90 | Engraving | 596 83 |
| | | Binding | 199 32 |
| | | Publishing Transactions | 2,757 75 |
| | | Badges | 200 90 |
| | | Certificates | 15 25 |
| | | Copyright (2 Years) | 10 00 |
| | | Engrossing Resolutions, etc. | 163 65 |
| | | Legal Expenses | 30 00 |
| | | Typewriter Exchanged | 77 50 |
| | | Catalogue Type | 3 75 |
| | | U. S. Bond *a/c.* Life Membership | 1,000 00 |
| | | U. S. Bond *a/c.* Reserve Fund | 1,000 00 |
| | | Premium on Bonds | 235 00 |
| | | Conversazione | 1,036 73 |
| | | Secretary's Balance to next year | 251 51 |
| | | Treasurer's Balance to next year | 1,451 48 |
| | $16,078 95 | | $16,078 95 |

Outstanding bills excepting $264.53 were paid in full April 27, 1901.

There is due the Institute $2,608.05, of which about one-half is probably collectible. The amount reported last year as overdue and probably collectible was $1,422.41. The actual collections have been $615.88.

The total receipts for the past year exceeded the previous year by $68.48, while the disbursements were $827.05 in excess of last year, showing an excess in growth of disbursements over the gain in receipts of $758.57. The net financial gain during the year was $1,476.43, as shown by the following summary:

| | |
|---|---|
| Net Cash Receipts | $13,617 39 |
| Disbursements, Excluding Bonds Purchased | 12,140 96 |
| | $1,476 43 |

Property on hand according to inventory May 1, 1901:

| | |
|---|---|
| Office Furniture and Fittings | $247 95 |
| Badges | 106 00 |
| Catalogue Type and Cases | 186 82 |
| Library | 1,615 00 |
| Transactions on Hand | 3,419 50 |
| Congress Books | 532 50 |
| | $6,107 77 |

TOTAL NET ASSETS.

| | |
|---|---|
| Treasurer's Cash Balance | $1,451 48 |
| Secretary's Cash Balance | 251 51 |
| U. S. Registered Bonds | 7,000 00 |
| Property as Inventoried | 6,107 77 |
| | $14,810 76 |
| Total Assets last year | 12,199 08 |
| Increase | $2,631 68 |

Respectfully submitted for the Council,

RALPH W. POPE,

*Secretary.*

## TREASURER'S REPORT.

FROM APRIL 30, 1900, TO MAY 1, 1901.

GEORGE A. HAMILTON, TREASURER, in Account with AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

*Dr.*

| | |
|---|---|
| Balance from April 30, 1900 | $2,905 08 |
| Received from Secretary, April 30, 1900, to May 1, 1901 | 13,622 36 |
| | $15,827 44 |

*Cr.*

| | |
|---|---|
| Disbursements from May 1, 1900, to May 1, 1901, on Warrants from Secretary, as approved by Council or Executive Committee, Nos. 1230 to 1357 inclusive | 14,375 96 |
| Balance to New Account | 1,451 48 |
| | $15,827 44 |

By direction of the Executive Committee the Secretary and Treasurer have purchased during the year $2000 in 5% Government Bonds, for which a premium of $235 was paid. These have been added to the funds existing last year, which now stand as follows:

| | Face Value. | Market Value. |
|---|---|---|
| Building Fund | $1,000 00 | $1,095 00 |
| Compounded Membership Fund | 3,000 00 | 3,285 00 |
| Reserve Fund | 3,000 00 | 3,285 00 |
| | $7,000 00 | $7,565 00 |
| Treasurer's Cash Balance in Bank, Carried Forward to next year | 1,451 48 | |
| | $8,451 48 | |

Respectfully submitted,

GEO. A. HAMILTON,

*Treasurer.*

It was voted that the reports as printed be accepted and filed.

REPORT OF PROXY COMMITTEE.

Mr. Maver read the report of the Committee on Proxies as follows:

| | | | |
|---|---|---|---|
| R. A. Byrnes | 1 | Cary T. Hutchinson | 1 |
| George F. Sever | 1 | Samuel Sheldon | 2 |
| William J. Hammer | 1 | A. E. Kennelly | 1 |
| Charles F. Scott | 1 | Cecil P. Poole | 1 |
| Edwin W. Hammer | 2 | Calvin W. Rice | 1 |
| Carl Hering | 3 | John J. Carty | 1 |
| W. A. Anthony | 1 | F. A. Pickernell | 1 |
| E. P. Thompson | 1 | George A. Hamilton | 2 |
| F. A. C. Perrine | 1 | Blank | 14 |
| Fitzhugh Townsend | 1 | Gano S. Dunn | 2 |
| William D. Weaver | 4 | L. B. Stillwell | 2 |
| Ralph W. Pope | 143 | | 198 |
| Francis B. Crocker | 2 | | |
| Charles P. Steinmetz | 8 | | |

WM. MAVER, JR.,
G. A. HAMILTON,
Proxy Committee.

The amended Constitution as reported by Council and printed in the April, 1901 issue of the TRANSACTIONS, was then taken up by the meeting for final consideration, and after considerable discussion was adopted by a vote of 56 affirmative and 3 negative, the proxies not being called for.

Dr. Arthur E. Kennelly then presented the following paper on "The New Edison Storage Battery."

[See page 331, May issue.]

## Discussion.

Dr. Kennelly:—Summing up, then, you will observe that the substances of which the cell is composed are steel and iron, those substances which are so enormously important in engineering generally. It is from steel and iron that the structures of mechanical and civil engineering are produced. It is steel and iron that have given us dynamos and dynamo-electric machinery for the transmission of electric power. Without steel and iron we would not be able to employ electricity commercially in such applications. Let us hope that steel and iron may be similarly the foundation of a great improvement in the storage cell. By a curious coincidence, all the active substances in this cell are distinctively magnetic—iron, nickel and the working substance, oxygen. The real difficulty presented, as Mr. Edison states it, was in finding salts of iron and nickel which would work, which would not remain passive, and I understand him to say that he has practically had to find new substances, in the sense of substances under conditions not recognized or known—virtually new salts, which would be capable of activity, of charging and discharging in this way.

Dr. N. S. Keith:—Mr. President, calling to mind the old adage that the "proof of the pudding is in the eating," we can add that it rests also in inverse ratio to a man's digestive disturbance, for good pudding. I do not wish to criticise this cell, because I have not figures enough, and have not facts enough under which to criticise. I hope that it is going to be all that is said for it this evening. But I notice that there is an absence of curves of charge to compare with the curves of discharge. It is by comparing those we determine the cost of storing and utilizing the electrical energy. We seem to have a new chemistry given to us, as well as a new electrolytic cell. We have here a mixture with graphite, a recognized strongly electro-negative material. I will grant you that graphite, iron and nickel have very little difference in their electro-motive forces when immersed in a solution of potassium hydroxide. But we have changes of those conditions. Under charge we get a so-called new oxide of nickel, something beyond a peroxide of nickel—a hitherto unknown thing, an exceedingly electro-negative material under the conditions, and it is associated with graphite, a less electro-negative; when told that there is no local action, to a chemist it seems there must be some mistake, or else there is a new chemistry. Then again, when we have oxide of iron we have a like condition of a highly electro-negative material, graphite, in combination, in close contact with a more highly electro-negative oxide of iron, and that there is no local action taking place seems to me at least astonishing. I will bow to results and say that he must be dealing out a little different chemistry from what we have been taught up to the present time. I think that we should not put out in a scientific paper read here a statement like this—that "the cell is an

oxygen lift;" that is, it is simply a transmitter of oxygen from one place to another, as though it was directly done—taken from one plate, carried over and put in the proper place on another. Electro-chemists know that no oxygen can be transferred from one place to another in an electrolyte without secondary actions and reactions taking place. I suggest that before this be put out to the world, it be modified on that point, so that we will not, as a scientific body, issue an imperfect statement of that kind. In general, common, every-day language, in explaining things to a layman, we might say that oxygen was taken from one and put over to the other. Well, it is; but it is done in a more complicated way than it would seem to be by the statement.

MR. CHAS. P. STEINMETZ:—The most striking feature of this new storage battery cell shown here, and especially striking to those who have anything to do with the lead accumulator, and especially those forms of lead accumulator in which an attempt is made to increase the output by reducing the weight—the most striking feature of this is the very solid and substantial mechanical construction. It is really a mechanical apparatus, apparently, and not a laboratory instrument, as the storage battery of the lead type actually is, or seems to be, and as experience seems to show it to be. I have no very extended experience; I have no very continued experience with lead storage batteries. I had an experience dating back to 1880, and I agree with Prof. Thomson when he told me once that he found a very satisfactory use for his lead storage battery—the best use he ever could put it to, and that was to melt it down and use it as a counter-weight in his telescope. There may undoubtedly be some very good use for the old material, and it has done some very good work, and is still doing work where weight is not essential, where you can have much weight and careful attendance. Still it is not a very mechanical structure, and this cell seems to offer certain advantages, and promises to be more mechanical and extremely neat, as we look at it here. As to the chemistry of this new cell, there seems to be something very mysterious—some peroxide which is very little known in chemistry. But we know that many of these metals, of the iron group especially, have iron oxides which are more or less stable, and at the same time I do not think we can make this an objection to the new accumulator, because no one has ever fathomed the chemistry of the lead accumulator, or come near to it. I stated that the most interesting and promising feature of the cell is the neat mechanical construction, which is very encouraging compared with other proposed and tried storage cells. Those people who know Mr. Edison's work will hardly find it astonishing, because we all probably agree that whenever Mr. Edison has brought out something, he has developed it mechanically so far that it is really a machine, a mechanical instrument, and not a laboratory toy.

MR. ROBT. MCA. LLOYD:—I think we ought all to be grateful

to Dr. Kennelly for his splendid presentation of this subject to-night. In the compass of a few pages he has laid before us a great deal of information for which we have been waiting.

I think we ought also to realize that this is the result of a long research by Mr. Edison, and that the INSTITUTE is fortunate in being the medium through which another great development in electrical science is made known to the world. While some of us have experimented with nickel and iron in storage batteries, I believe Mr. Edison has carried his investigations in this subject much further than anyone else, and the plates shown us to-night are worthy not only of our interest, but of our greatest admiration. On the other hand, I do not agree with Mr. Steinmetz in his statement that this is a mechanical success as compared with the old lead storage batteries. We have yet to find out the difficulties with this finely constructed iron instrument. It is hardly likely that it will last forever, and probably it will not be as ideal as we all hope it will be. These iron structures may possibly deteriorate in the presence of electrolysis, and the fact that has been suggested to us of the presence of graphite, points to other possible difficulties besides local action. There also seems to be a suggestion in Dr. Kennelly's paper that there is local action, inasmuch as he speaks of "initial voltage of discharge after receiving the charge." I would like to ask him whether any noticeable change had occurred in the voltage after standing on charge. The mean voltage is rather low compared with the initial voltage of the charge. Perhaps I did not understand his exposition of the curves, but from the mean voltage being 1.1 volts it looks as if the voltage must fall at times down to near half a volt. A large part of the capacity of the cell must therefore be delivered at a low voltage. The internal resistance is certainly high, quite as high as the internal resistance of the average storage battery in proportion to its watt capacity. The solution is also going to be troublesome if it is not chemically pure, because iron and other things are very likely to get into water, and of course are going to make trouble in that battery. Perhaps iron would not have any very serious effect, but there are many kinds of water which would very likely muddle up those briquettes of nickel in the course of two or three years. And looking at it broadly, it seems to me hardly likely that these fine plates and those briquettes are going to maintain their mechanical or chemical constituency for a very much longer period than the clumsy old lead laboratory instrument with which we are all familiar. The lead battery is clumsy, but after all it is just about as commercial, as far as we know, as this is likely to be. I do not feel that we have had enough experience with these cells to be able to predict anything about them. I only hope that they will be all that Mr. Edison believes them to be.

THE PRESIDENT:—If there is no further discussion, I would like to ask Dr. Kennelly whether the solution does not have to

be protected from the air? I do not recall whether this is referred to in the paper.

DR. KENNELLY:—It is not mentioned in the paper.

THE PRESIDENT:—The trouble with the use of caustic potash in batteries of that kind is that it changes into the carbonate when in contact with the air, and it must therefore be protected with a layer of oil or something similar.

I would also like to ask whether there is not a strong corroding action on the lugs of the plates along the surface of the liquid, where both the air and the liquid are jointly or alternately in contact with the lugs of the plates.

MR. MAILLOUX:—I would like to ask Dr. Kennelly if he could give us some even approximate data in regard to the efficiency of the battery. He has given the mean voltage of discharge. Could he give us also the mean voltage of charge, so that we might obtain what Regnier has so aptly called the "coefficient of drop" or the ratio of the mean E. M. F. of discharge to that of charge? Could he also give us the mean ampere-hours of charge, so that we might obtain what Regnier also so aptly calls the "coefficient of restitution," or the ratio of the discharge ampere-hours to the charge ampere hours; that is, the relative yield in ampere-hours; the product of which two coefficients gives the absolute efficiency of a battery. In other words, could he give us either in watt-hours the amount of energy required to fully charge the cell to obtain a good normal discharge, or could he give us separately the two factors, voltage and amperes?

MR. H. G. STOTT:—There is one point I notice about this battery which in a practical way might be rather troublesome, and that is that the initial voltage of discharge is 1.5 volts. The mean point of discharge is stated as approximately 1.1 volts. There is a drop of about 26.6 per cent. Now, that change of voltage would have to be taken care of in practice by either a booster or end cells. I would like to ask how rapidly this fall of pressure takes place.

In the lead cell the voltage falls immediately from 2.5 to 2.2 as soon as the charge stops, and the practical discharging voltage is between the limits 2.1 and 1.8, or a variation of 14.3%, whereas with the Edison cell there is apparently a drop of 26.6%—calling for practically double the regulating apparatus necessary with the lead cell.

DR. KENNELLY:—I will do the best I can to answer the questions that have been put. In regard to the charging electromotive force, it commences at about 1.5 and ends about 1.6, and I suppose that 1.55 would be about the mean charging voltage. The discharging mean voltage of 1.1 includes a discharge carried down to as low as .3. As you saw on the last diagram (Fig. 8), if you carry the discharge only as low as one volt, the mean terminal potential difference of discharge would be more like 1.25 volts. Consequently, under those conditions, with a some-

what reduced output, you would have a fall between 1.55 and 1.25.

As regards the graphite, I believe that that does not enter into any chemical action whatsoever. Whether it might ultimately do so on forcing the cell to extreme overcharge, I do not know; but it appears to be inert, according to the statements I have received. Its purpose is to improve the conductivity of the briquettes. I believe there is no sensible loss by local action. Mr. Edison states, in the passage I have quoted, that after a nickel plate was taken out and dried for a week, its ampere-hour capacity and, I suppose, also its watt hour capacity, was not appreciably affected.

As regards the oxygen-lift question, I know that that is a rather popular way of expressing the matter, but I think it is justified in so far as we deal with the general resulting action. In the charged condition there is a relative superabundance of oxygen at the negative plate. In the discharged condition, there is a relative superabundance of oxygen at the positive plate. In charging, therefore, oxygen is transferred against the forces of chemical affinity from the positive to the negative plate. In discharging, the oxygen is transferred with the forces of chemical affinity. Now the action, of course, by which that transfer takes place is much more complicated, and I have not attempted to carry it out; in fact, I do not know it. Unless we all know accurately what the compound was and just exactly what that salt of nickel was—it is only assumed to be nickel peroxide—we could not attempt to map exactly the actions that occur. But whatever those actions may be, we know, broadly speaking, that after discharge there is more oxygen with the iron and less with the nickel, and on the contrary, the oxygen is transferred in charging; also that is the only ultimate change apparently taking place in the cell. It is fair to say, from a general, broad standpoint, that by charging you have lifted the oxygen away from chemical affinity and have pulled it out of its natural position, and when you let the cell discharge, you reverse that operation and allow the oxygen to return. Whether there are intermediate steps by which the ions go in different directions, etc., is a matter which we need not concern ourselves about and which it does not profit us at the first glance to enter into. When the chemistry of the subject is better understood, then these minute actions and the more correct phenomena will be all understood.

I think I have answered Mr. Steinmetz's question. As regards $NiO^2$, the voltage fall is not, as I understand it, attributable to local action. The voltage fall is due, I presume, to a superficial exhaustion of the briquettes, and the consequent interposition of an obstacle to the action of the undischarged briquettes in their interior, and I suppose that fall of electro-motive force is due to the superficial layer of discharged substance. The drop in the cell is of course that permanent fall plus the $IR$ drop. I do not think that I can answer accurately the questions concerning the

precise amount of that current-resistance drop at different loads. I have not made any succession or series of observations upon the cells myself, and I only take the figures and results that have been given to me, and there is about 10% drop at a 3½ hour rate.

As regards the troubles from the solution, if not chemically pure, I suppose that may be safely admitted. If you do not have pure solutions you may have trouble, and it may be necessary perhaps to occlude the solution, as is done now with the Edison-Lalande cells, or in some other manner.

In regard to the volume comparison, I have not made any careful comparison. The cell is very compact, as you see, and it is essentially a steel cell as against a lead cell. It will be compact both by virtue of the thinness of the plates and by virtue of the small separation or clearance between the two. The coefficient of efficiency, so far as I know it, is simply represented by the comparison between the mean charging voltage of 1.55 approximately, and the discharging voltage of about 1.25, if you carry the discharge to the 1 volt point.

As to the ampere-hour coefficient I do not know that.

I think that I have answered most of the questions which have been put to me.

MR. JUSTUS B. ENTZ:—I have experimented with both iron, steel and nickel plates, in alkaline solution, and, as Dr. Kennelly says, it is difficult to reduce the oxide or oxidize the pure metal. The higher oxide of iron that I have seen produced electrolytically under these conditions was soluble in the solution. There is apparently some intermediate oxide that is capable of being raised to a higher point and lowered again. I have never run across anything like it, and the composition of the cells was totally unexpected. The general difficulty which I have seen with the two metal cells as compared with the one metal cell like the lead battery, is local action; if in a lead battery any material from the positive plate should come off and get into the solution and attach itself to the negative, it will immediately be reduced to spongy lead and become part of the negative plate. There is no loss of energy except as represented by that amount of peroxide. But in any two metal cell, as this; if nickel, for instance, which has a difference of potential from that of reduced iron, should get on the iron plate, local action would go on indefinitely. So that the presence of the slightest amount of material from the positive on the negative would create a local action which would go on indefinitely. That has been one of the greatest objections to a cell composed of different metals, and not simply oxides and reduced metal of the same metal, as in the lead cell; the alkaline solution itself, in my experience, has got to be covered with a layer of oil. I have also found it has quite a high internal resistance unless it is kept at a high temperature. With the copper-zinc cells it was necessary to keep the solution at a temperature of about 130° to enable it to do any commercial

work. In regard to lead batteries such as are used to-day, a battery is being used very extensively which has a capacity of about 12 watt-hours per pound. Of course batteries can be constructed, and commercial batteries too, up to 15, 16, and more watt-hours per pound; but to day a battery having a capacity of 12 watt-hours per pound and weighing from 30 to 35% of the weight of the vehicle will propel an automobile between 40 and 60 miles, according to the general size of the vehicle. That takes up quite a space in the vehicle. As this new battery has a less specific weight than the lead cell of the same capacity per pound, so, weight for weight, this style of cell would necessarily be more bulky.

DR. KENNELLY.—In giving these figures, you refer to the alkaline cell, not the lead cell.

MR. ENTZ:—Oh, yes, lead cells of a type such as have done about 100,000 miles last month in automobile service.[1]

MR. MAILLOUX:—There are several mysteries about this cell, more especially about the chemical structure and the reaction of the iron; but there is another thing which seems to me far more mysterious, if the explanation given be the whole explanation. We have heard of the transfer of oxygen and the reference to a means for "lifting the oxygen." Now, if the reaction involved be one which concerns oxygen only, then we have a mysterious case of selective electrolysis in which we have the evolution of ions only at one pole. Now, we know of no case in electrolysis where we have an anion without a cation. Certainly in this case, if the ordinary laws of electrolysis apply, every time that oxygen is transferred, a corresponding cation must also be transferred, not only during the charge, but during the discharge. I surmise that this must be the case in this particular instance, and that hydrogen must be the corresponding cation which is evolved. We know that iron can be reduced to its metallic state from its oxides by the action of hydrogen, and there are several forms of finely reduced iron, including the kind known as "iron by hydrogen" in pharmacy. Reduction of oxygen merely takes place by the operation of hydrogen in some form or other, in the nascent state, so-called, or in the peculiar condition evolved as an ion at the cathode. It would be interesting to have Dr. Kennelly state whether he has not heard from Mr. Edison that hydrogen performed its part in the mystery of the reactions of this battery. As for the O which he has used on the black board, to represent

1. The lead battery referred to is to-day largely employed by the New York Elec. Vehicle Transportation Co., 100 batteries are now in service and are doing an average mileage of 1,000 miles a month, while in some cases the average service is as high as 1,200 miles a month, and up to date 2,500 to 3 000 miles have been run with one set of batteries. The total mileage, on one charge, in the large electric broughams and hansoms, such as are commonly seen on the streets, is from 45 to 50 miles, in regular service.

the mysterious undefined quantity of oxygen entering into the combination; I think it would be well to put a little sub "n" or a little sub "x" after the O.

DR. KENNELLY:—Of course it goes without saying that you cannot have an oxygen ion or a hydroxyl ion going one way without having a corresponding cation the other way. But all I maintain is that according to the results which have been stated to me, the solution is unaltered, and the salts which are formed in charge and discharge differ from each other essentially only in the oxygen or hydrated oxygen contents. The resultant change is essentially an oxygen change. The transfer of the cation may produce temporary chemical change, but no resultant change in the electrolyte.

MR. MAILLOUX:—That is just exactly where I would differ from Dr. Kennelly. I would submit that unless gases be evolved there during the charge or discharge, then there must be a transportation of hydrogen ions to the cation side, and I would submit that those ions are quite as important in the reaction as the oxygen ions, and that no complete formula of the action which takes place can be made without taking into consideration the amount of energy necessary for that change of condition of the hydrogen or its transfer. There must necessarily be a transfer of hydrogen from the one plate to the other; when the oxygen goes to the positive plate the hydrogen goes to the negative, and in the reverse action of the battery the reverse process must take place. It is equally certain that the complete reactions cannot be examined electrolytically or electrothermically without taking into consideration both of those constituents.

MR. EDWARD P. THOMPSON:—Speaking about spongy iron—I understand that spongy iron was formed—of course that is iron with an absorbed gas, and that gas is probably hydrogen.

DR. WILLIAMS:—I do not see any reason for bringing hydrogen into this at all. Potassium is what does migrate there. Potassium could be the reducing agent at the electrodes, it seems to me, unless hydrogen were found to be generated at the electrodes as gas.

MR. MAILLOUX:—I accept the modification, because potassium might replace hydrogen, being also a strong electropositive substance. If, however, potassium is actually transferred, the solution density will not remain unchanged in charge and discharge.

MR. CHAS. J. REED:—It seems to me that this battery is an exceedingly interesting one, and I for one feel like congratulating Mr. Edison on the results he has attained. The battery is interesting from a chemical standpoint, being of an entirely different type from any of the accumulators that have ever been put into practical use. There have been recently some others working in the same field, who have produced batteries of this particular type, but of other materials, not using iron or nickel. I had occasion recently to examine such a battery and was somewhat

surprised at the results, some of which were exceedingly interesting. In the particular case that I refer to, a battery weighing about six pounds gave, in its best condition, a capacity of 80 ampere-hours with an average electromotive force of one volt, or something like 16 watt-hours per pound of complete cell. One

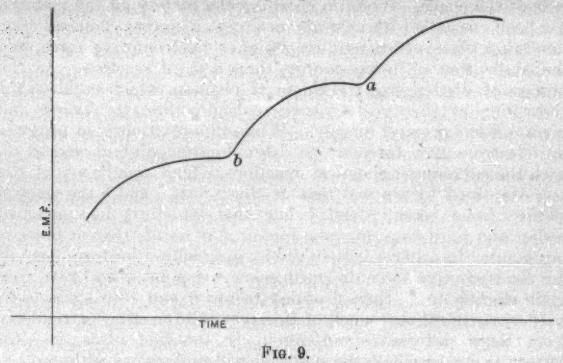



FIG. 9.

peculiarity in this particular cell was, that it showed in a much more marked degree than this battery of Mr. Edison the successive chemical changes which take place in the cell. The curves of charge and discharge, instead of being straight or being single

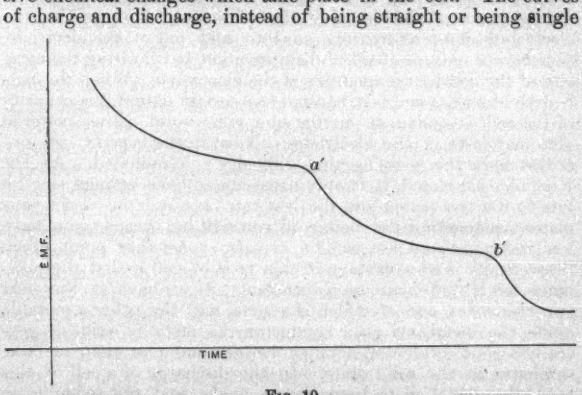



FIG. 10.

curves, were made up of several curves. The charge curve was of the form shown in Fig. 9. The electro-motive force at the beginning of the charge being about one volt, and at the end of the charge about two volts. The discharge curve was as shown in Fig. 10, the point *a* of the charging curve corresponding to the

point $a^1$ in the discharge curve, and the point $b$ corresponding to $b^1$, showing evidently that the electrical energy is not produced from a single chemical reaction, but that there are several chemical reactions taking place in succession. During the early part of the charge there is a chemical change which corresponds to one part of the curve. When in charging the battery all the material has been converted into certain products, a second chemical reaction takes place which requires a higher electromotive force, and the absorption of more energy, then a third reaction. In the process of discharging, the chemical reaction, which required the absorption or the greatest energy, begins first to reverse and gives out the greatest energy. While this reaction is in progress the electromotive force drops down to the point $a^1$, and so on with the subsequent chemical reactions. One peculiarity of the cell examined by me was that at the points $a$ and $b$ the electromotive force actually fell below that which it had attained earlier and in discharging rose higher at $a^1$ and $b^1$ than at preceding points. In other words, in discharging with a uniform current the electromotive force dropped below the point $a^1$ and then rose again slightly to $a^1$, then dropped below $b^1$ and rose again to $b^1$.

It seems to me that a cell of this type is interesting particularly from three different standpoints. In the first place, an ideal battery is one in which the material will undergo as little motion as possible; the material which enters into the chemical reaction will remain in a certain fixed place. In any cell, in which the electrolyte takes part in the chemical action and combines with the substance of the electrode, that of course is impossible; the electrolyte must alternately go into and out of the electrode, causing not only mechanical disintegration but limiting the capacity of the cell by the quantity of the electrolyte. When the electrolyte of such a cell is exhausted to a certain extent, the capacity of the cell is ended, no matter how much solid active material you may have in the elcctrodes. Now, in the type of cell described here this evening that difficulty is eliminated. As Dr. Kennelly has stated, it is only necessary to have enough electrolyte to wet the plates, and the less you have and the closer your plates are together the better off you will be, because you have less resistance and less weight to carry. Another point which theoretically is of advantage in this type of cell is that the resistance tends to remain more constant. If we have at the start two electrodes, one of which is a metal and the other a metallic oxide, the metal is a good conductor, the metallic oxide is generally a good conductor, a much better conductor than metallic sulphates in the solid state. In the discharge of a cell of this type, the metal plate becomes an oxide, and the oxide plate becomes a metal. The change in resistance in general we should not expect to be so great as where a metal and a conducting oxide both became a non-conducting sulphate such as we have in the lead cell. Experience with the various types of alkaline zinc-copper batteries have shown that this is the case.

There is one other chemical reason why this cell is exceedingly interesting. It may not be practical, but it points to a possibility which many of us have been looking for. If we suppose these plates to be made very thin, so that they could easily be washed; for example, if we imagine a battery to be constructed in such a way that we have a thin film of the metal on one plate and a thin film of oxide on the other, so that the alkaline solution could easily be washed out, it does not require a great stretch of imagination to step away from the dynamo altogether. In other words, when this battery is discharged, we can take the plates out of the solution, drain them off, wash out the alkali, and then we have simply got our oxygen transferred from one plate to the other as Dr. Kennelly has explained. What we want to do is to transfer the oxygen back again. Now, there are other ways besides electro-chemical action in which that can be done. For example, we have in this particular battery, assuming the formula given in the paper to represent the reaction, nickel hyper-oxide, as it is called in the paper, on one plate and metallic iron in a finely divided state on the other plate. The discharge of this battery would naturally result in the production of ferrous oxide and nickel monoxide. That would be the first step at least. Whether that would be final or not I would not want to say. But metallic iron would certainly not reduce the nickel to the metallic state unless the electro-motive force dropped to something like two tenths of a volt, as the difference between the formation heats of nickel monoxide and ferrous oxide is very little. That of nickel monoxide is about sixty-one calories and that of ferrous oxide about sixty-nine. But suppose we have this battery in a discharged state. The nickel hyper-oxide is reduced to nickel monoxide; metallic iron is oxidized to ferrous oxide and we have the plates cleaned from impurities. It is a well-known fact that ferrous oxide can be converted back into metallic iron by simply heating it to about 300° C. in the presence of hydrogen, and it can also be done with carbon monoxide. It is possible also to find other ways by a dry or other thermo-chemical process of producing nickel peroxide or hyper-oxide, as it is called in the paper. I do not mean to say that we can charge this particular battery in this way, but I am speaking now in general of this type of battery. With iron I think it could very probably be accomplished. But if we should succeed in working out a thermo-chemical process for reducing the iron and re-oxidizing the nickel oxide, then we could charge this battery without the use of any dynamo or any electric current. In other words, the battery is not only a storage battery, but it is an instrument for transforming heat and chemical energy from other sources, such as carbon, carbon monoxide, or hydrogen into electrical energy. That would not, of course, be a direct process of getting electrical energy out of carbon; yet it might be an economical process. I think, therefore, that a cell of this type is interesting from these three reasons particularly.

The theoretical capacity of such a cell would be about 160 ampere hours per pound of active material, while that of the lead cell is about 44 ampere-hours. I do not see any particular reason in the abstract why we should not be able to actually utilize as high a percentage of the total active material in this cell as in the lead cell. In fact, it seems to me that we might utilize a higher percentage from the very nature of this cell, because products formed by discharge are not non-conductors as in the case of the lead cell. One of the reasons why we can only utilize a small percentage of the material in the lead cell is that the product of discharge is a non-conducting substance which obstructs the current; whereas in this case the products on both electrodes remain conductors, the only difference being that the oxygen has changed from one plate to the other.

THE PRESIDENT:—What happens when a very strong charging current is sent through the cell; and what gases are developed then, if any? It would also be interesting to know something about the life of the cell; whether it has been charged or discharged frequently enough to show what the effect of repeated charges would be. I would also like to ask Dr. Kennelly whether that double knee in the discharge curve is due to a different chemical action than that in the main discharge, or perhaps to the fact that one of the plates was discharged, while the other was not; does he know whether both the plates had gone through the first chemical reaction when the first knee was reached, and then went through a second to the second knee.?

DR. KENNELLY:—In regard to the first question, if the battery is heavily charged, gas is given off, certainly hydrogen is given off, and I have seen that effect taking place from the outside of the windows.

THE PRESIDENT:—Hydrogen on one and oxygen on the other, I suppose?

DR. KENNELLY:—I presume so. I am sure of the hydrogen; I am not sure about the oxygen. In regard to the durability of the battery, I am unable to make any personal statement. Mr. Edison has been working on the cell for a number of months, and he tells me he has had experimental cells charging and discharging repeatedly for some months without observing any depreciation in them. A cell of this kind requires special tools for its manufacture; a press, for example, which will bring 100 tons stress upon a plate, is a matter of some difficulty to obtain, and as a result it takes time to produce the first samples of a plate of the kind. The result of that has been that Mr. Edison has conducted his experiments entirely on some plates consisting of a small number of these pockets as distinguished from a completed plate of twenty-four. But of course the results obtained from the small number of pockets are capable of reduplication in the ordinary way, just as putting cells in quantity in the ordinary voltaic battery.

As regards the knee in the discharge curve, it must be produced by a chemical exhaustion of some sort, either on the positive or on the negative plate, and the knee itself does not tell you as to whether the exhaustion has occurred upon one or upon the other or upon both. I believe that in this particular instance Mr. Edison attributes the knee to the exhaustion of the positive plate, as distinguished from the negative, which simply means that with more of the positive acting substance in that particular pair of elements, the knee would have been deferred beyond the limits of the diagram.

MR. CHAS. J. REED:—It seems to me that it is a very reason-supposition. We have in this case iron which in oxidizing to the ferrous state would probably give up most of the energy of the cell, and we know that ferrous oxide is easily converted and spontaneously goes over into ferric oxide. The change from ferrous to ferric oxide would not evolve as much energy as the change from iron to ferrous oxide, so that we would get a much lower electro-motive force when the current is developed by the conversion of the ferrous oxide into the ferric than we would before. In the cell which I have mentioned, my own conclusion was that one of those bends or angles in the curve was produced by the exhaustion of material on one plate, and the other by exhaustion of material on the other plate. The materials of each plate in that case seemed to undergo two successive chemical reactions.

MR. H. E. HEATH:—I would like to ask Dr. Kennelly if, from his paper, we should not understand that the chemical or electrolytic action is confined entirely to the active material; because I notice that in the paper it states that the covers for the briquettes are in both plates covered with nickel. Naturally, if there is any electrolytic action then between the nickel and the plates, we should have it at least at the iron plate; but the metals present are all of them in a pure state inert in the solution, and, as nearly as I can understand from the paper, the chemical or electrolytic action is confined entirely to the briquettes and the pure metals present only act of conductors.

DR. KENNELLY:—The gentleman is correct.

MR. STEINMETZ:—I believe we will all agree that this has been one of the most interesting papers which has been presented here for a very long time, and also that all will agree with me when I move a vote of thanks of the INSTITUTE, particularly to Mr. Edison for his kindness in permitting the development of his work to be publicly described before our INSTITUTE; and also a vote of thanks to Dr. Kennelly for having taken the pains and the great interest in our INSTITUTE to prepare this paper and arrange for its presentation.

[Carried unanimously.]

DR. KENNELLY:—So far as Mr. Edison is concerned I am sure he will be very gratified to hear of your motion. I can only say that I am more than gratified

THE PRESIDENT:—As there seems to be no further discussion, I would like, with your permission, to say a few words before leaving the Chair to my successor.

Neither our old nor our new Constitution gives your retiring President an occasion to address you, and as it is now somewhat late in the evening, I will not take up your time to do so, but I would like to take the present opportunity to thank you once more for having honored me with the presidency during the past year, especially as that year was a somewhat important one for the INSTITUTE, owing to the holding of our first meeting in a foreign country. I also wish to thank you all, especially my colleagues in office, for the many kind courtesies that have been extended to me while in office. It gives me great pleasure to say that the work of the Council during the year has been carried on with complete harmony in every detail. I would like also to express to you my great appreciation and admiration of the excellent and creditable work done by our committees, many of the members of which have worked most energetically and unselfishly in the interests of the INSTITUTE and in many cases at considerable personal sacrifice. That the committees have been successful in most if not all their work, you will no doubt agree with me. Their work was rendered all the more difficult as there were a number of new features in the affairs of the INSTITUTE during the past year, among which may be mentioned our first meeting abroad, which was the beginning of what promise to be very interesting and profitable international associations; the *Conversazione*, which was such a complete success and has given the INSTITUTE considerable prominence; the preparing of the new and much needed Constitution; the successful revival of the annual dinner, which promotes the very desirable social intercourse between the members; our assistance in securing the passage by Congress of the much needed National Bureau of Standards; and last, but by no means least, the munificent gift by Dr. Wheeler, of the very valuable Clark library, accompanied by the generous gift of Mr. Carnegie of equal money value. The good example set by Dr. Wheeler promises to be followed by donations from other members and will hasten very materially the realization of our long felt want of a building and home for our INSTITUTE. All these things have been accomplished by the faithful and energetic work of our committees, and by my colleagues in office, and I take great pleasure in expressing to you my appreciation of their work.

The report of the tellers is now in order.

## TELLERS' REPORT.

NEW YORK, May 21st, 1901.

To the President and Members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Gentlemen:—

The following is the result of the counting of the ballots for the election of officers:

| | | |
|---|---|---|
| Total ballots received | | 485 |
| Discarded as follows: | | |
| Ballots bearing no name | 23 | |
| Defective ballots | 23 | |
| Ballot of resigned member | 1 | 47 |
| Total ballots counted | | 438 |

### FOR PRESIDENT

| | | | |
|---|---|---|---|
| Charles P. Steinmetz | 395 | T. A. Edison | 1 |
| L. B Stillwell | 26 | C. O. Mailloux | 1 |
| M. I. Pupin | 12 | Chas. F. Scott | 1 |
| C. S. Bradley | 1 | Wm. Stanley | 1 |

### FOR VICE-PRESIDENTS.

| | | | |
|---|---|---|---|
| Samuel Sheldon | 417 | Carl Hering | 1 |
| George F. Sever | 409 | C. T. Hutchinson | 1 |
| M. I. Pupin | 402 | J. P. Jackson | 1 |
| C. O. Mailloux | 8 | A. E. Kennelly | 1 |
| C. P. Steinmetz | 8 | Philip Lange | 1 |
| B. J. Arnold | 6 | George P. Low | 1 |
| C. S. Bradley | 3 | R. T. Lozier | 1 |
| Louis Bell | 2 | Wm. Maver, Jr. | 1 |
| C. F. Brackett | 2 | F. A. Pattison | 1 |
| J. J. Carty | 2 | F. A. C. Perrine | 1 |
| D. C. Jackson | 2 | W. L. Robb | 1 |
| Herbert Lloyd | 1 | L. B. Stillwell | 1 |
| C. R. Cross | 1 | W. D. Weaver | 1 |
| Louis Duncan | 1 | S. S. Wheeler | 1 |
| I. H. Farnham | 1 | J. G. White | 1 |
| G. H. Guy | 1 | | |

### FOR MANAGERS.

| | | | |
|---|---|---|---|
| Chas. F. Scott | 427 | F. O. Blackwell | 1 |
| J. W. Lieb, Jr | 425 | J. B. Blood | 1 |
| Samuel Reber | 412 | H. W. Buck | 1 |
| W. E. Goldsborough | 396 | W. C. Burton | 1 |
| A. L. Rohrer | 5 | J. B. Cahoon | 1 |
| Eskil Berg | 4 | H. S. Carhart | 1 |
| W. J. Hammer | 3 | H. C. Cushing, Jr | 1 |
| C. D. Haskins | 2 | F. B. Crocker | 1 |
| D. C. Jackson | 2 | W. C. L. Eglin | 1 |
| H. A. Lardner | 2 | R. T. Lozier | 1 |
| T. C. Martin | 2 | M. Oudin | 1 |
| Townsend Wolcott | 2 | W. L. Puffer | 1 |
| A. H. Armstrong | 1 | F. B. Rae | 1 |
| B. J. Arnold | 1 | F. S. Smith | 1 |
| F. Bedell | 1 | L. B. Stillwell | 1 |
| Louis Bell | 1 | | |

### FOR TREASURER.

G. A. Hamilton ..... 438

### FOR SECRETARY.

| | | | |
|---|---|---|---|
| Ralph W. Pope | 436 | W. J. Hammer | 1 |

Respectfully submitted,

EDWARD CALDWELL,
RALPH W. POPE, (Acting)
Tellers.

THE PRESIDENT:—You have heard the report of the tellers of the election. If no motion to the contrary is made, the report will be accepted and filed. I hereby declare that the following officers have been duly elected for the ensuing year: Chas. P. Steinmetz, President; Dr. Michael I. Pupin, Dr. Samuel Sheldon, Prof. George F. Sever, Vice-Presidents; John W. Lieb, Jr., Charles F. Scott, Prof. W. E. Goldsborough, Col. Samuel Reber, Managers; George A. Hamilton, Treasurer; Ralph W. Pope, Secretary.

Although the term of office of our newly elected President does not begin until after the adjournment of the present meeting, I feel sure that you will overlook the transgression, if I ask him to preside at the closing of this meeting. If there are no objections, I take great pleasure in asking my distinguished successor and highly esteemed colleague, Mr. Chas. P. Steinmetz, to take the Chair. [Applause.]

MR. STEINMETZ:—Gentlemen, I feel highly gratified by the great honor you have conferred on me in electing me your President, and I assure you I shall endeavor to do all that is in my power to come up to the high standard in my presidency which has been set by the President of our INSTITUTE preceding me, and I shall do all that I can to satisfy you and to sustain the standard of the INSTITUTE and increase its importance so far as I shall be able to during the year to come.

I believe the business before the house to-night is completed in an extremely satisfactory manner, if you consider that we have at last succeeded in adopting the new Constitution, I should think, the time being late, that a vote to adjourn would now be in order. The next meeting will be our annual convention.

[Adjourned.]

*A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 21st, 1901.*

[ADVANCE COPY—SUBJECT TO REVISION.]

# SYNCHRONISM AND FREQUENCY INDICATION.

BY PAUL M. LINCOLN.

## I.—Synchronism Indicator.

It has long been recognized that the operation of paralleling alternators makes desirable the use of some more sensitive method than the usual synchronizing lamps so extensively employed in the past, and which are to-day most generally used for indicating synchronism. The obvious lack of sensitiveness on the part of lamps, when used for synchronizing, has led in many cases to the substitution of voltmeters, with a considerable improvement in the accuracy of the indications. There is still, however, much to be desired on the score of sensitiveness in indicating the point of synchronism, and this point is one which is becoming more and more important as the size of alternators become larger and their regulation stiffer.

The synchronism indicator described in the following pages is new, so far as the writer is aware, and he trusts that its analysis may be of interest to the members of the Institute.

Suppose a stationary coil F has suspended within it a coil A, free to move about an axis in the planes of both coils and including a diameter of each. If an alternating current be passed through both coils, A will take up a position with its plane parallel to F. If now the currents in A and F be reversed with respect to each other, coil A will take up a position 180° from its former position. Reversal of the relative directions of currents in A and F is equivalent to changing their phase relations by 180°, and therefore this change of 180° in phase relations is followed by a corresponding change of 180° in their mechanical relations.

Suppose now that instead of reversing the relative direction of currents in A and F, the change in phase relations between them be made gradually and without disturbing the current strength in either coil. It is evident that when the phase difference between A and F reaches 90° the force between A and F will become reduced to zero and a movable system, of which A may be made a part, is in condition to take up any position demanded by any other force. Let a second member of this movable system consist of coil B, which may be fastened rigidly to coil A, with its plane 90° from that of coil A, and the axis of A passing through a diameter of B. Further suppose a current to circulate through B, whose difference in phase relative to that in A, is always 90°. It is evident under these conditions that when the difference in phase between A and F is 90°, the movable system will take up a position such that B is parallel to F, because the force between A and F is zero, and the force between B and F is a maximum; similarly when the difference in phase between B and F is 90°, A will be parallel to F. That is, beginning with a phase difference between A and F of 0, a phase change of 90° will be followed by a mechanical change in the movable system of 90°, and each successive change of 90° in phase will be followed by a corresponding mechanical change of 90°. To investigate the mechanical relations corresponding to intermediate phase relations, suppose the phase difference between A and F to be 0. The force between A and F will then be a maximum, and that between B and F, 0. Now suppose a small change in phase between A and F to take place. The force between A and F becomes slightly less than the maximum, and that between B and F becomes other than 0. The movable system will take up the position of equilibrium between forces on A and B, which will be somewhere intermediate between A parallel to F, and B parallel to F. It is further evident that the direction of motion of the movable system depends upon the sign of the differential change, so that such a device is not only responsive to a change of phase between A and F, but is also responsive to the direction of that change.

It may be interesting to note that quadrature between A and B is not absolutely necessary either in the mechanical angle between A and B, or in the phase angle between their currents. So long as there is a displacement between A and B, both mechanical and electrical, the device is responsive to phase changes between A and F.

The above is a brief description of the principles upon which rests this new synchronism indicator. Connect coil F to a set of bus bars, and coils A and B to a dynamo that is to be paralleled to those bus bars and in the motion of movable coils, there is a constant index of the phase condition of the dynamo with respect to the bus bars. Fig. 1 shows a photograph of a synchronism indicator built on the above principles and installed in the power-house of the Niagara Falls Power Company, where it has been in successful operation for some time. This instrument is mounted on a swivel so that it can be made to face any one of the dynamos to be synchronized by its use. This mounting makes

FIG. 1.

it possible for the attendant handling the paralleling switch, as well as the one who controls the speed of the dynamo, to see the instrument, and be fully informed as to the condition of the dynamo with respect to synchronism.

In the construction of the device shown in Fig. 1, a laminated iron magnetic circuit is used and the phase difference between A and B is secured by using a non-inductive resistance in series with one coil, and an inductance in series with the other. It is of course impossible to secure 90° phase difference in this manner, but sufficient difference can be obtained to answer all practical purposes. Current is introduced

into the armature through three slip rings, one of the rings being made to do duty for one end of both armature windings.

The ideal synchronizing device should perform three functions.

1. It should tell the amount of difference in frequency.
2. It should tell whether the machine being synchronized is running too fast or too slow.
3. It should tell the exact point of synchronism.

Comparing the above described device with devices now ordinarily in use for the purpose of synchronizing, in regard to these criteria, we find:

1. In regard to the first point, no difference obtains.
2. In regard to the second point, the new device gives complete information, while ordinary devices give none.
3. In regard to the third and most vital point, usual devices give only partial information, while that given by the new device is complete not only at the point of synchronism, but at every other point in the cycle.

The experience of the Niagara Falls Power Company with this new synchronizer has been most gratifying. The average time required to synchronize a dynamo has been divided by at least two, and the incipient welding of switch contacts which occasionally occurred with the old method of synchronizing, due to dynamos going in slightly out of step, has been entirely obviated. The switchboard attendant seems to feel, when synchronizing a dynamo, a degree of confidence which was impossible under former conditions.

It may be of interest to derive an expression giving at all points in the cycle the exact relations between mechanical and phase angles in such a device as is above described. It will also be of interest to determine the behavior of the device when the electrical and mechanical angles between A and B are other than 90° and other conditions to be mentioned later.

In Fig. 2 let F F be the plane of the field, O A the plane of armature coil, A and O B the plane of armature coil B. In the discussion hereafter $\theta$ will always represent the mechanical angle between F F and O A and $\varphi$ will always represent the electrical angle between their currents.

We shall assume

I. That the electrical angle between the currents in O A and O B is 90°.

II. That the mechanical angle between windings of A and B is 90°.

III. That the ampere turns in A and B are equal.

IV. That the current in armature element A is in phase with its E.M.F.

V. That the E.M.F. produced in the armature windings by the field and vice versa is neglible.

VI. That the E.M.F. wave produced by the rotation of the armature in the field is a sine wave.

VII. That the waves impressed upon the device are sine waves.

With these assumptions we have force on A as,

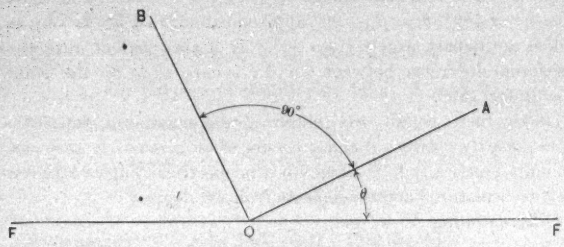



FIG. 2.

(1) $F_1 = K \sin\theta \cos\varphi$, and the force on $B$ is

(2) $F_2 = K \sin(\theta + 90^0) \cos(\varphi \pm 90^0)$, whence

(3) $F_2 = \pm K \cos\theta \sin\varphi$.

For equilibrium $F_1 + F_2 = 0$, whence

(4) $\sin\theta \cos\varphi = \pm \cos\theta \sin\varphi$

(5) $\tan\theta = \pm \tan\varphi$

(6) $\theta = \pm\varphi$ or $\pm(\varphi + 180^0)$

The double signs indicate that the direction of rotation of $\theta$ with respect to $\varphi$ depends upon the sine of the angle between the two armature currents. The two values 180° apart indicate two points of equilibrium in the cycle. One of these is evidently a point of unstable equilibrium.

If now the electrical angle between the two armature wind-

ings is other than 90°, the above will be modified as follows,

Force on A is:

$$F_1 = K \sin\theta \cos\varphi \tag{7}$$

and force on B is:

$$F_2 = K \sin(\theta + 90^0) \cos(\varphi \pm \beta) \tag{8}$$

Where $\beta$ is the electrical angle between the currents in the two armature windings.

For equilibrium:

$$\tan\theta = \pm \sin\beta \tan\varphi - \cos\beta \tag{9}$$

From this it is seen that when $\varphi = \pm 90°$, $\theta = \pm 90°$, and when $\varphi = 0°$ or $180°$, $\theta = \beta - 90°$ approximately, that is, so long as $\beta$ does not depart largely from 90°. It is also evident that the maximum difference between $\theta$ and $\varphi$ occurs close to the point $\varphi = 0°$ or $180°$.

Under these conditions, therefore, the maximum departure from equality between $\theta$ and $\varphi$ occurs when $\varphi$ is nearly zero and amounts practically to the amount the electrical angle between the two armature currents departs from 90 degrees.

Differentiating (9) we get:

$$\frac{d\theta}{d\varphi} = \pm \sin\beta \frac{\cos^2\theta}{\cos^2\varphi} = \frac{\cos^2\theta\cos^2\beta \pm 2\sin\theta\cos\theta\cos\beta + 1}{\sin\beta} \tag{10}$$

Which is an expression for the sensitiveness of the device. That is, if the electrical angle is varying at a constant rate, the above expression gives the rate at which the mechanical angle varies. An inspection of the above expression shows that supersensitive and hypersensitive points exist on diameters at about the points $\theta = \pm 45°$.

The exact points of super- and hypersensitiveness are

$$\theta = \tan^{-1}\frac{\cos\beta}{2} \pm \sqrt{1 + \frac{\cos^2\beta}{4}} \tag{11}$$

The effect of these super- and hypersensitive points is to cause an acceleration and retardation of the synchronizer indicator hand at certain points in the phase cycle even when the phase change is taking place at a perfectly even rate.

If desired, however, this variation due to departure of electrical angle from ninety degrees may be completely compensated for by adjusting the mechanical angle between the two armature windings so that it is equal to the supplement of the electrical angle between their currents. Proof of this is as follows:

Force on armature winding A is

$$F_1 = K \sin\theta \cos\varphi$$

and force on armature winding B is

$$F_2 = K \sin(\theta + \alpha) \cos(\theta \pm \beta)$$

Where $\alpha$ is the mechanical angle between the two armature windings and $\beta$ is the electrical angle between their currents.

For equilibrium

$$\sin\theta \cos\varphi = -\sin(\theta + \alpha) \cos(\varphi \pm \beta) \tag{12}$$

For purpose of simplifying take $\theta_1 = \theta + \alpha$.

Substituting and expanding we have

$$\sin\theta_1 \cos\alpha \cos\varphi - \cos\theta_1 \sin\alpha \cos\varphi = -\sin\theta_1 \cos\varphi \cos\beta \pm \sin\theta_1 \sin\varphi \sin\beta \tag{13}$$

By making $\alpha = 180° - \beta$, this becomes

$$\cos\theta_1 \cos\varphi = \pm \sin\theta_1 \sin\varphi \quad \text{whence} \tag{14}$$

$$\theta = \pm(\varphi + \alpha \pm 90°) \tag{15}$$

From this it appears that the difference between the mechanical and electrical angles is always a constant when the mechanical angle between the two armature currents is made equal to the supplement of the electrical angle between their currents, provided the ampere turns in the two armature elements are equal.

Now to consider the result of making one of the armature windings stronger than the other. Supposing other conditions to remain as per our assumptions on page 439 we have force on winding A is

$$F_1 = K_1 \sin\theta \cos\varphi \tag{16}$$

and force on B is

$$F_2 = K_2 \cos\theta \sin\varphi \tag{17}$$

When equilibrium exists:

$$K_1 \sin\theta \cos\varphi = K_2 \cos\theta \sin\varphi \tag{18}$$

$$\tan\theta = \frac{K_2}{K_1} \tan\varphi \tag{19}$$

Whence

$$\frac{d\theta}{d\varphi} = \frac{K_1}{K_2} \sin^2\theta + \frac{K_2}{K_1} \cos^2\theta \tag{20}$$

From this it appears that at and near the diameter 0°–180° the device is supersensitive, and hypersensitive at and near the diameter + 90° to — 90°, when $K_2 > K_1$.

If $K_1 > K_2$ the super- and hypersensitive points are reversed. It is further evident that super- and hypersensitive points may be made to occur at any desired point in the cycle by a combination of the methods above cited.

For the purpose of a synchronism indicator it is usually preferable to dispense with any supersensitiveness at the point of synchronism for the reason that supersensitiveness at any point tends to give the indicating hand a jerky motion, setting up vibration of the armature across the point of equilibrium.

## II.—Frequency Indicator.

The problem of frequency measurement is one which has from time to time attracted the attention of experimenters and designers as a result of which a number of different devices have been proposed and tried with more or less success. My excuse for adding one more to the number of devices proposed for this purpose is that the device herein described not only gives a beautiful theoretical solution of the problem, but also bears out its promise in actual practice so far as it has been tried.

It may seem somewhat peculiar to describe in a single paper two so dissimilar devices as a synchronism indicator and a frequency indicator. The reason for this is that the two devices were conceived and developed almost simultaneously and are very similar to each other in principle and design. One was, in fact, a direct development of the other.

The synchronism indicator described in the first part of this paper is in reality a phase meter, in that it gives a continual indication of the phase relations between the currents in its field and armature. If now the current in one of these elements can be made to change its phase with reference to that in the other,

due to a change in frequency, the device will evidently become a frequency indicator.

This result can be effectually obtained by inserting a capacity in series with the inductance of the field. The phase relations between the E. M. F. and currents in the armature remain practically unchanged with varying frequency while under the above condition; that between the E. M. F. and current in the field, plus the added capacity, is sensitive to frequency change. The angu-

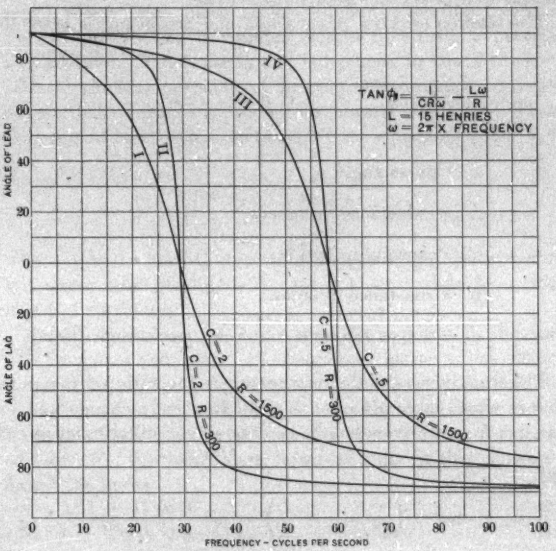



FIG. 3.

lar position assumed by the armature is an indication of the phase relation between currents in field and armature, and is therefore a measure of frequency. Assuming then that an angular movement of the armature always represents an equal angular shift of phase between currents in it and the field, it is only necessary to determine the phase change in the field for a given frequency change to obtain a complete calibration of this frequency indicator.

Fig. 3 gives for a number of different conditions, the relations

between frequency and phase angle in circuits containing inductance, capacity and resistance. These curves show that the most rapid change of phase angle for a given frequency change occurs at the point where the phase angle is 0.

When phase angle is 0, resonance exists; that is the capacity ohms at that point are equal to the inductive ohms. It will be interesting to determine how great a frequency change is indicated by a given phase angle change both at the point of resonance as well as at other points in the cycle.

The relation between phase angle and frequency is given by

$$\tan \varphi = \frac{1}{C R \omega} - \frac{L \omega}{R} \tag{21}$$

In which

$\varphi$ = phase angle.

$L$ = inductance in henrys.

$C$ = capacity in farads.

$R$ = resistance in ohms.

$\omega = 2 \pi \times$ frequency in cycles per second.

The sensitiveness of the instrument is the ratio of the phase change which takes place for a small frequency change and expression for sensitiveness may be obtained by differentiating (21)

$$\frac{d \varphi}{d \omega} = - \cos^2 \varphi \left( \frac{1}{C R \omega^2} + \frac{L}{R} \right) = \frac{C R (1 + C L \omega^2)}{(1 - C L \omega^2)^2 + C^2 R^2 \omega^2} \tag{22}$$

Resonance occurs when

$$\omega^2 = \frac{1}{C L}$$

and if this value be substituted in (22) it becomes

$$\frac{d \varphi}{d \omega} = - \frac{2 L}{R} \tag{23}$$

This is the expression for sensitiveness at the point of re-

sonance, at which point it reaches a maximum. The angular change in degrees for a 1% change in frequency at resonance is

$$\frac{7.2\ L\ n}{R}$$

in which $n$ is frequency in cycles per second.

The usual service required of a frequency indicator is the measurement of the small variations from normal frequency or speed which take place under ordinary operating conditions. For this purpose the instrument herein described is peculiarly well adapted. The capacity and inductance in the field circuit, both of which are capable of accurate measurement, can be so chosen that resonance is produced at normal frequency. That is, they should be chosen so as to satisfy the equation

$$(2\ \pi\ n_0)^2 = \omega_0^2 = \frac{1}{C\ L}$$

where $n_0$ is the normal operating frequency. The instrument will under these conditions be used at a point where its sensitiveness is a maximum.

Sensitiveness, however, is not the only requisite in the design of a frequency indicator. Its range is a matter which deserves a share of attention. Considering (21) it is evident that when $\omega = 0$, $\varphi = +\ 90°$, and when $\omega = \infty$, $\varphi = -\ 90°$. All frequencies of positive sign are therefore included in this total range of 180°. Of this total range, however, only in that portion between the limits

$$\varphi = \tan^{-1} \pm \sqrt{\frac{L\ \omega_0}{L\ \omega_0 \pm R}} \tag{24}$$

is the sensitiveness above one-half the maximum. The corresponding limits for the frequency are given by

$$\omega = \sqrt{\omega_0^2 \pm \frac{R}{L}\ \omega_0} \tag{25}$$

That portion of the scale between these two limits may be taken as the working range. This working range occupies approximately 90° of the scale extending from approximately plus 45° to

minus 45°. The frequency included between these two limits is approximately expressed by

$$\frac{R}{2\pi L}$$

As might be expected the expressions for sensitiveness and range are reciprocal quantities; as one increases the other decreases.

So far we have been proceeding on an assumption of the use of a perfect phase meter; that is, one whose phase angle changes are exactly reproduced by mechanical angle changes the same in amount.

Methods of obtaining super- or hypersensitive points of mechanical angle, change with respect to phase angle change are given in the first part of this paper. These methods are as applicable to this frequency meter as the synchronism indicator. For instance, suppose it is desired to carry sensitiveness at the point of resonance to a point beyond the possible limits of

$$\frac{2L}{R}$$

This can evidently be accomplished by diminishing that armature current whose phase nearest coincides with that of the field current. By this means sensitiveness may be carried to any limit desired.

By certain modifications an instrument may be made to possess the double advantage of long range and extreme sensitiveness. Adjust an instrument to extreme sensitiveness at resonance by properly fixing the ratio of the two armature elements. Now by placing in series with the field an adjustable capacity or an adjustable inductance, or both, the normal frequency to be measured may be brought within the comparatively narrow range of the instrument, and the frequency to which the instrument is adjusted may be found by noting the values of inductance and capacity in circuit. Or we can go a step further and omit entirely that armature element which is in phase with the impressed E. M. F. Then by adjusting the inductance and capacity in the field circuit so that there is no torque exerted on that armature element whose current differs by ninety degrees from the E. M. F. impressed on the

field, the frequency of the impressed E. M. F. is measured directly by

$$\sqrt{\frac{1}{C\,L}} \times \frac{1}{2\,\pi}$$

In applying this device to the frequency measurements of a power or lighting circuit, the most natural method of obtaining the phase difference required by the two armature elements, is to connect a non-inductive resistance in series with one of them and an inductive resistance in series with the other. Although it is impossible by this method to reach a phase difference of 90°, it can be nearly enough approximated to answer every purpose. There is one advantage which pertains to this method of obtaining the phase difference between the armature elements. The current in the inductive element is inversely proportional to frequency, and since sensitiveness at the point of resonance is directly proportional to this ratio, the expression (23) becomes

$$\frac{d\,\theta}{d\,\omega} = -\frac{2\,L}{R}\,\frac{\omega_1}{\omega} \tag{26}$$

and the instrument's indication in degrees for a one per cent. change of frequency becomes

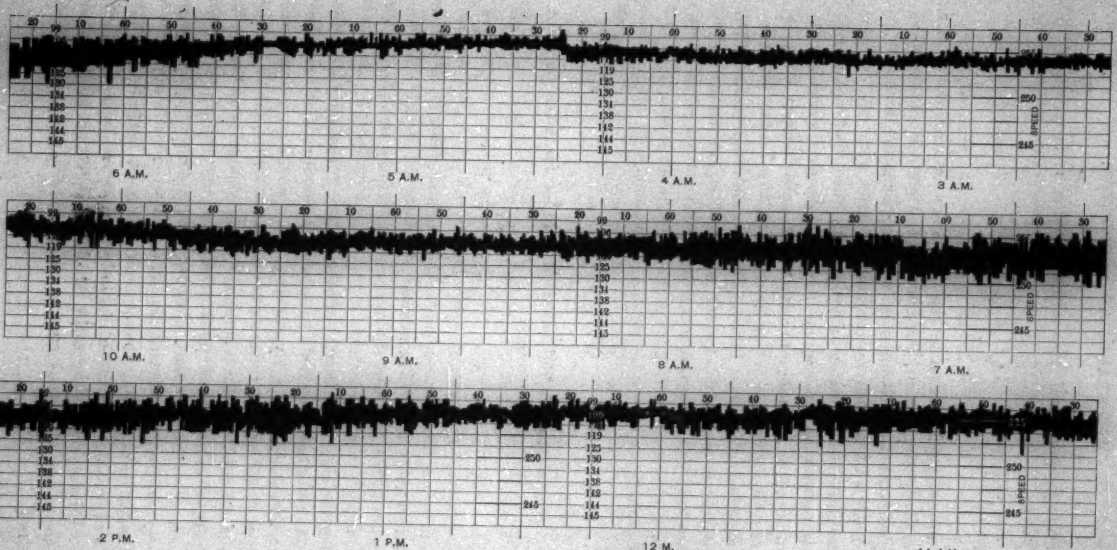
$$\frac{7.2\,L\,n_1}{R} \tag{27}$$

$n_1$ and $\omega_1$ are here the frequency and angular velocity at which the currents in the two armature elements are equal. Advantage lies in the fact that the expression (27) is independent of frequency.

The device is evidently applicable to the measurement of the speed of any rotating body by attaching thereto a small alternating current dynamo. By making the dynamo two-phase, the proper phase relation for armature elements of the meter can be easily obtained. One advantage of using this style of meter is that its indications are dependent only on the frequency of impulses transmitted thereto, and are independent of the voltage applied, so long as it is sufficient to operate the instrument.

It may be interesting to enumerate the most apparent advantages of frequency or speed indicator such as has been described.

1. First its point of greatest sensitiveness comes at the point of normal speed or frequency at which point it is, as a rule, most desired.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8 A.M.
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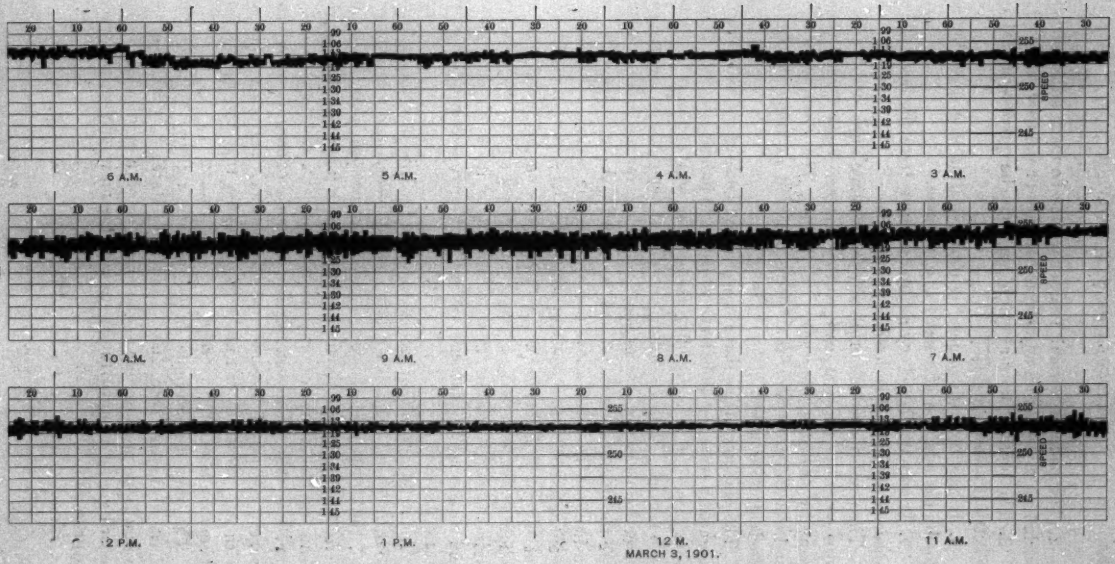
12 M.
12 NOON JAN. 16, 1901.
11 A.M.
SPEED

FIG. 4.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2 P.M.
1 P.M.
12 M.
11 A.M.
SPEED
MARCH 3, 1901.

Fig. 5.

2. The point of normal frequency may be made adjustable by including in circuit an adjustable capacity or inductance.

3. The point of normal frequency may be predetermined by electrical measurements.

4. It may be made general in its application as a speed indicator by the addition of a small A. C. dynamo.

5. It may be placed any desired distance from the body whose speed of rotation it is desired to measure.

The condition which originally led to the design of this apparatus was the complaint made to the Niagara Falls Power Company by its distributing agent in Buffalo, The Cataract Power and Conduit Company, that there occurred at times an undue fluctuation of speed.

The tachometers at that time used by the Niagara Falls Power Company were not sufficiently sensitive to indicate the fluctuation complained of. A recording tachometer was obtained and put into service. This recording instrument depended on centrifugal force for its action, but its sensitiveness was far too small to measure the fluctuations we wished to record. A conception of the instrument described above occurred to the writer. An instrument was made up, a pen was attached to its armature and it was set to recording the frequency fluctuations on the Buffalo circuit where it has been doing successful duty ever since. So far as the writer is aware it is the first instrument of its kind ever made, and its success has induced the writer to give a description of it to the INSTITUTE.

A few sample speed records as made by this instrument may be of interest. Figure 4 shows a speed record made on January 16, 1901. At first glance the speed fluctuations seem to be severe, but when it is remembered that each horizontal line represents a speed change of only one-half per cent. and that the speed curve is that of a water-driven dynamo operating on a load largely composed of street railway service, engineers familiar with the difficulties will undoubtedly agree that the results obtained are above the average.

The very considerable improvement exhibited between the chart of January 16th, 1901, and that of March 3, 1901, [Fig. 5] is in a large measure due to the existence of a continuous speed record giving an opportunity to note the most efficient governor adjustments.

*A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 21st, 1901.*

[ADVANCE COPY, SUBJECT TO REVISION.]

# PERFORMANCE OF AN ARTIFICIAL FORTY-MILE TRANSMISSION LINE.

BY WILLIAM S. ALDRICH AND GEORGE W. REDFIELD.

The artificial duplication and test of a 40-mile transmission line was carried out as far as facilities would permit in the Electrical Engineering Laboratory of the University of Illinois during the Spring semester of 1901. The combinations selected were such as would cover a wide range of conditions in practice. The results obtained represent closely those that might be expected under commercial conditions of a similar line. The characteristics of performance illustrate the evil effects of shifting phase displacement as the chief cause of poor regulation.

*General Considerations and Requirements.*—The kind of service and requirements at the receiver end of the line involve a consideration of the kind of load, such as synchronous motors or converters, induction motors, arc and incandescent lights, or any combination of these. In the design of the line the prime factors are load, distance, voltage, frequency and allowable drop and loss. There is usually allowed a maximum drop for the given conditions. Such an allowance depends upon the kind of service employed, the character of the load and the inherent properties of the line, such as ohmic resistance, self-inductance, capacity, frequency, line current and its phase displacement.

The character and variation of receiver loads also largely influence the line regulation, losses and efficiency. The voltage, cost of conductors, cost of construction and maintenance and insulation to prevent leakage deserve some share of consideration.

The energy or $I^2R$ loss in the line, in per cent. of the full load power delivered to the line, usually varies between 5 and 10%, in the best modern transmission installations. The charging current and receiver wattless components of current, if any, will indirectly vary this $I^2R$ loss according to whether they are neutralized or not.

*Effect of Reactive Loads Upon Line Efficiency.*—The effects of reactive loads upon the performance of the generator are well understood and have been set forth in numerous experiments. The effect of such loads upon the transmission is to increase the current for the same energy transmitted over that required when

FIG. 1.—Coils for Artificial Reactances.

the current in the line is in phase with its impressed E. M. F., the line loss increasing, as the square of the current will be much increased with increase of phase displacement. From this consideration alone it would appear that the line current should be in phase with its E. M. F. for most efficient performance. Considering, however, the voltage and drop for a given amount of power delivered, it is to be noted that conditions may arise in practice in which an inductive line may transmit energy at a higher efficiency than a non-inductive one.

*Conditions Assumed.*—It is desired to transmit, by three-phase system, with step-up and step-down transformation, from 1 to 8 K. W., 40.75 miles, at 2,300 volts and 64 cycles, with a transmission efficiency, between generator terminals and receiver secondary terminals, of not less than 80%, at full and practically non-inductive load on the receiver secondary circuit. The size and frequency were necessarily determined by the polyphase generator available.

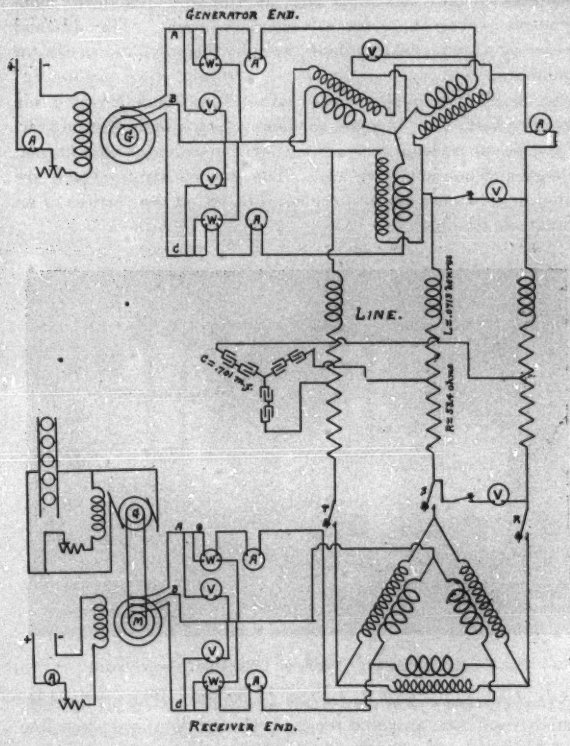
No. 4 (B. & S. gauge) copper wire was selected, giving a line loss per phase of 0.215 K. W., or about 8%, on a basis of 2.66 K. W. output per phase from receiver secondary terminals, under normal voltage and non-inductive load. The line constants chosen are suited to a distance apart of the wires of 18″ at the vertices of an equilateral triangle.

FIG. 2.—Arrangement of Artificial Line Above Switchboard.

*Self-Inductance and Inductive Reactance.*—The artificial inductive reactance provided for each wire of the three-phase line was an air-core coil wound and adjusted to the proper self-inductance of this line wire under the conditions assumed. Maxwell's bridge method[1] was used in standardizing these three inductances. The accuracy of the standard inductance and resistances used and the sensitiveness of the galvanometer warranted an accuracy to within one-fifth of 1%. Air-core coils were selected to insure

1. Maxwell's "Electricity and Magnetism," vol. ii., p. 367.

that such equivalent inductance of the artificial line (and therefore its reactance at constant frequency) would remain constant throughout all variations of line current. These reactance coils, Fig. 1, were each immersed in earthenware jars filled with a high




CONNECTIONS FOR TESTS OF 40-MILE ARTIFICIAL TRANSMISSION LINE.

FIG. 3.

grade of transformer oil and always used in this condition. While in use they attained a temperature of approximately 70° C., and remained practically at this temperature during the experiment. The resistance of each coil at this temperature was 9.0 ohms.

*Ohmic Resistance.*—The total ohmic resistance of each line wire for the given conditions should be 53.4 ohms. To supply the remaining 44.4 ohms for each line wire, three non-inductive resistances were constructed by winding No. 17 (B. & S. gauge) German silver wire non-inductively upon frames, as shown above the switchboard, Fig. 2. These resistances were each adjusted by an accurate Wheatstone bridge to the value of 44.4 ohms, at about 85° F., the temperature of the room.

*Capacity and Capacity Reactance.*—The artificial capacity of the three-phase line was composed of six commercial electrostatic condensers, two condensers each being connected in series and thence connected in star between the three line wires. These condensers were arranged so that the capacity between each of the line wires and the neutral was 0.701 micro-farads. The outer terminals of the star-connected condensers were respectively connected to the middle points of the non-inductive resistances of each line wire, Fig. 3. Such an arrangement was equivalent to concentrating all of the capacity of the 40.75–mile transmission line midway between the generator and receiver ends.

TABLE I.

DATA OF ARTIFICIAL TRANSMISSION LINE.

| | |
|---|---|
| Length of transmission | 40.75 miles |
| Diameter of conductors, No. 4 B. & S. | 0.204 inches |
| Area of conductors | 41,742 cir. mils. |
| Resistance per mile at 75° F. | 1.31 ohms |
| Frequency, cycles per second | 64 |

CONSTANTS OF THE LINE COMPUTED FROM THE ABOVE DATA.

| | |
|---|---|
| Inductance per mile of wire or ½ mile of transmission | 0.001750 henrys |
| Inductive reactance per mile of wire, 64 p. p. s. | 0.703 ohms |
| Impedance per mile of wire, 64 p. p. s | 1.487 ohms |
| Impedance factor of line (impedance divided by resistance) | 1.134 |
| Resistance of 40.75–mile transmission line (or 81.50 miles of line wire) | 106.8 ohms |
| Inductance of 40.75–mile transmission line (or 81.50 miles of line wire) | 0.1426 henrys |
| Inductive reactance of 40.75–mile transmission line, 64 p. p. s. | 57.3 ohms |
| Impedance of 40.75–mile transmission line, 64 p. p. s | 121.2 ohms |
| Capacity of each wire to neutral per mile of transmission line | 0.01732 m. f. |
| Capacity reactance between two wires per mile of transmission at 64 p. p. s. | 1,449,300 ohms |

| | |
|---|---|
| Capacity of 40.75-mile transmission line considered as two parallel cylinders | 0.701 m. f. |
| Capacity reactance between two wires of 40.75-mile transmission line | 355,300 ohms |
| Charging current per phase of 40.75-mile transmission, 64 p. p. s. and 2,300 volts | 0.374 amperes |
| Total apparent energy to charge line, 64 p. p. s. and 2,300 volts | 1.49 K. W. |
| Total true energy to charge line, 64 p. p. s. and 2,300 volts, or total $I^2R$ due to charging current | 0.011 K. W. |
| Current per phase to transmit 8 K. W. at 2,300 volts and unity power factor | 2.01 amperes |

TABLE II.

DATA OF THE ARTIFICIAL SUBSTITUTES FOR LINE CONSTANTS.

| | |
|---|---|
| Size of wire of reactance coil for each line wire | No. 18 B. & S. gauge |
| Inside diameter of each reactance coil | 1.87 inches |
| Outside diameter of each reactance coil | 4.0 inches |
| Length of each reactance coil | 14.25 inches |
| Approximate number of turns on each reactance coil | 1,420 turns |
| Inductance of each reactance coil | 0.0718 henrys |
| Ohmic resistance of each reactance coil, 70° C | 9.0 ohms |
| Resistance of non-inductive portion of each line wire | 44.4 ohms |
| Total ohmic resistance of each artificial line | 53.4 ohms |
| Equivalent artificial capacity per phase of each line wire to neutral | 0.701 m. f. |

*Connections Used in Operation.*—The reactance coils were placed at the receiver end, all of the line reactance being assumed as concentrated at that point. In series with each of these reactance coils was placed one of the non-inductive resistances, with its respective condensers.

The connections of apparatus and instruments for the various experiments are shown in Fig. 3. In the experiments for charging current and resonant rise the switches R, S and T were open.

*Description of the Generator.*—Three-phase current was generated from a machine made by the Westinghouse Electric and Manufacturing Company, constructed for single and polyphase work, as generator, synchronous motor or converter. The armature has a distributed winding, and was here tapped off as a three-phase delta combination.

DIMENSIONS AND MEASUREMENTS OF GENERATOR.

| | |
|---|---|
| Type | Polyphase converter |
| Serial number | 135,751 |
| Capacity | 10 kilowatts |
| Number of poles | 4 |
| R. P. M. | 1,920 |

| | |
|---|---|
| Frequency | 64 cycles |
| Normal volts (three-phase) | 410 |
| Full-load current per branch (three-phase) | 14 amperes |
| Resistance of field (hot) | 685 ohms |
| Resistance of armature per phase (hot) | 0.92 ohms |

*External Characteristics of Generator.*—External characteristics were taken of this machine under various reactive loads with lagging and leading phase displacement[1]. The results are shown

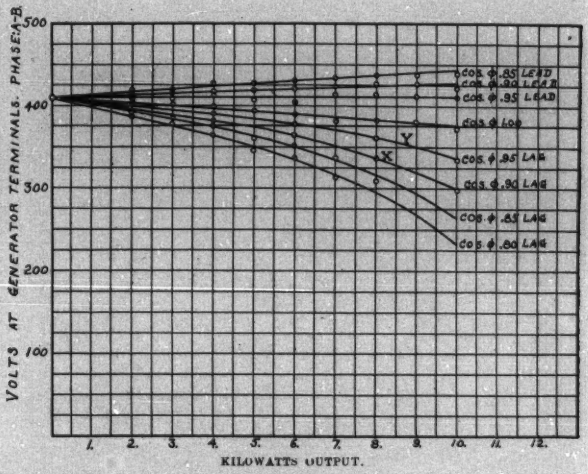



FIG. 4. External characteristics of Westinghouse 10 K.W. Alternator as three-phase Generator, showing the effect of Variable Reactive Loads on Regulation.

in Fig. 4. In obtaining each of these curves the true power was measured by the two-wattmeter method. The power factor of the external circuit was kept constant throughout the whole range of load by maintaining constant the ratio of the two-wattmeter readings.[2]

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1 "The Regulation of Alternators under Variable Reactive Loads." Geo. W. Redfield, *Technograph*, University of Illinois. No. 15, p. 95, 1901.

2 "Power Factor Measurements." B. Frankenfield. *Electrical World and Engineer*, vol. 35; p. 178. Feb. 3, 1900.

*Charging Current of the Artificial Line.*—The receiver end was open-circuited and the charging current measured as on a three-phase line. One of the line wires at the generator end was

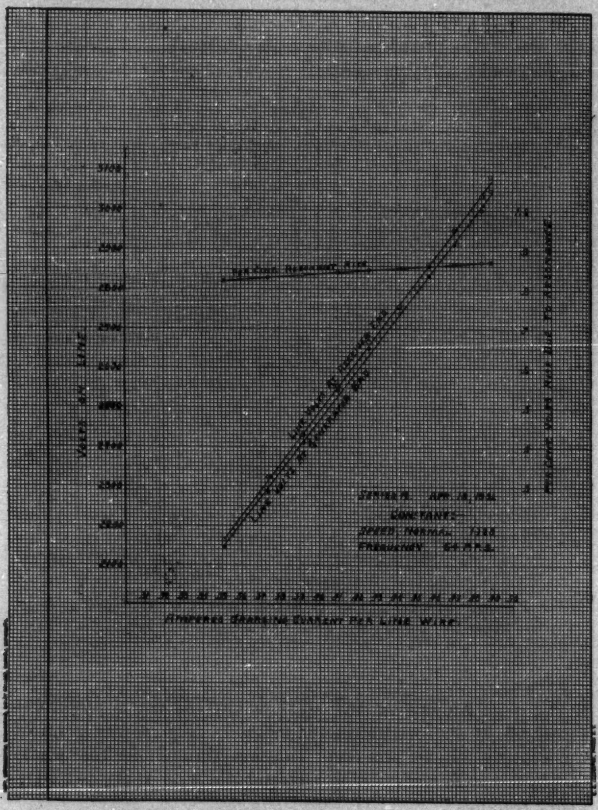

FIG. 5.—Relation Between Charging Current and Resonant Rise for Various Voltages at Generator End.

disconnected and the charging current measured with the same voltage and frequency applied to the line as before. In the case of the three-phase line the total charging current was $2/\sqrt{3}$ that of the charging current of the single phase line.

*Resonant Rise*—An experiment was made to determine the rise of voltage at the receiver end primarily due to resonance. The line at the receiver end was opened and a Weston

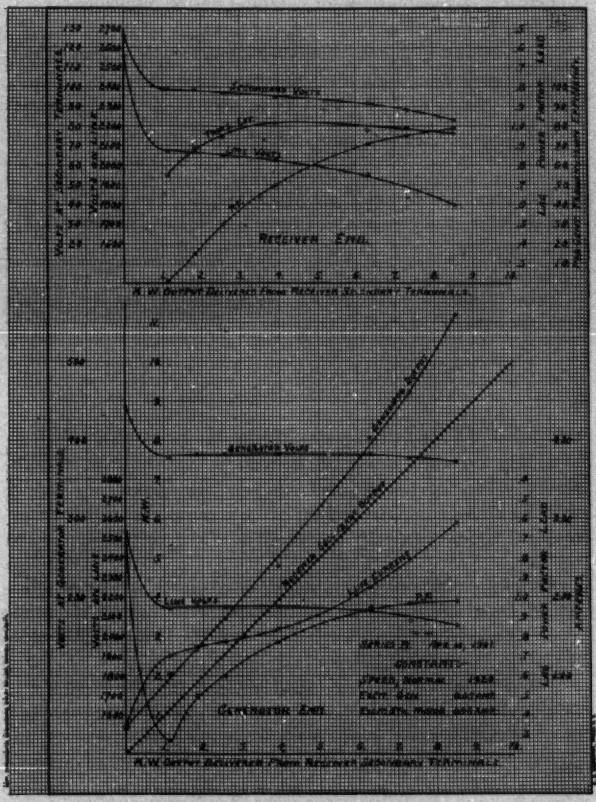


Fig. 6.—Performance of Transmission at Variable Load with Under-Excited Synchronous Motor.

voltmeter, with suitable multiplier, was then placed across the terminal of one of the phases. Fig. 5 shows the results of this experiment, giving the relation between charging cur-

rent and resonant rise for various voltages at generator end. During the interval when the charging current was measured the voltmeter was not in circuit, and hence there was no current taken off the line at the receiver end.

Let $e$ = percentage rise of potential due to resonance.[3]

$C$ = total capacity of line, in farads.

$L$ = inductance in henrys, of total length of one circuit.

$\omega = 2\pi n$, where $n$ is the frequency or p.p.s.

$$\text{Then, } e = \frac{C\,\omega\,L\,\omega\,100}{2}$$

The quantities $C$ and $L$ are proportional to the length of line and therefore the percentage rise in potential varies practically as the square of the length of the line and the square of the frequency.

Substituting in this formula the values for the 40.75-mile line, we have,

$$e = \frac{10^{-6}\times 0.701\times 401.5\times(0.0713\times 2)\times 401.5\times 100}{2} = 0.816$$

this being the calculated per cent. rise due to resonance for this line. By a glance at Fig. 5, it will be noticed that the observed values for the per cent. resonant rise agree very closely with the above computed value. It also shows that this per cent. resonant rise is practically independent of the voltage applied to the line.

All power factor values of the three-phase circuit were determined from two-wattmeter measurements by use of the well-known curve of ratios of wattmeter readings in connection with the cosine curves for balanced three-phase system.[1]

*Power Factor at Generator End on Open Receiver Secondary.*—When the receiver secondary circuit is open it will be noticed in all of the curves of performance that the power factor at the generator end is leading. The reason for this will be evident upon considering a series of readings by the two-wattmeter method, one or the other wattmeter always having the larger

3. "The Use of Aluminium Line Wire, and Some Constants for Transmission Lines," by F. A. C. Perrine and F. G. Baum, TRANSACTIONS, vol. xvii., p. 345.

1. Ibid. Frankenfield.

reading according to whether the resultant power factor of the three-phase line is leading or lagging. The current in the line under these given conditions is known to be leading because the charging current is in excess of the no-load current required by the transformers. Further evidence that the power factor at the generator end is leading is shown by the line voltage at the receiver end being higher than the line voltage at the generator end, and such a condition could not be possible, owing to the inductance of the line unless there was a leading current in the line. For no-load on the secondary, at the receiver end, similar conditions are obtained in all subsequent tests; hence, the resulting leading power factor of the three-phase transmission is the same in all cases of open receiver secondary.

*Description of the Synchronous Motor.*—The transmitted power was absorbed at the receiver end by a machine made by the General Electric Company, constructed for single and polyphase work, as a generator, synchronous motor or converter. The armature has a distributed winding and and was used as a three-phase machine.

DESCRIPTION OF SYNCHRONOUS MOTOR.

| | |
|---|---|
| Type | Synchronous Machine. |
| Capacity | 7½ K.W. |
| No. of poles | 4. |
| R. P. M. | 1920. |
| Frequency | 64 cycles |
| Normal voltage (three phase) | 110 |
| Full load current per branch (three-phase) | 40 amp. |

*Performance of Transmission at Variable Load with Under-Excited Synchronous Motor.*—The curves of performance, Fig. 6, show that as soon as the synchronous motor is thrown on, as a lightly loaded receiver, at constant excitation of 0.96 amperes, taking about 1.1 K.W., the phase displacement at the generator end immediately changes from lead to lag. The line current rises quite rapidly and the high-tension and low-tension pressures at each end drop considerably, due to the presence of lagging currents in the line and generator circuit. Under such conditions the regulation of the generator is greatly impaired, as shown in Fig. 4. The under-excited synchronous motor is similar in its effects upon the transmission system to an induction motor, producing lagging phase displacement materially affecting the regulation of the system. As the load in-

creases, the line drop at receiver end falls off gradually, while the current comes rapidly into phase with the impressed E.M.F., reaching unity power factor at a trifle over full load. This effect

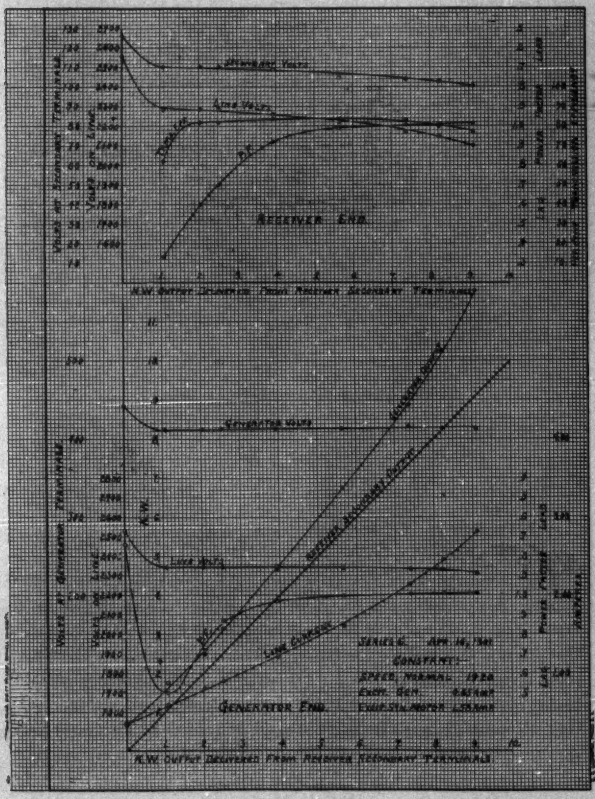


FIG. 7.—Performance with Normally-Excited Synchronous Motor.

partially compensates for the increased drop due to heavier loads and therefore has a tendency to keep the voltages up. The phase displacement at the receiver end controls the phase relations of

these E.M.F.'s. The line current is exceptionally high under light loads, because under such conditions the receiver power factor is very low.

$$\text{Transmission efficiency} = \frac{\text{Output of receiver secondary}}{\text{Input from generator terminals}}$$

The efficiency in this case reaches a maximum value of 82%, at about half load, and has a maintained value of 80% and over from one-third to two-third load.

*Performance with Normally Excited Synchronous Motor.*— The characteristics under this condition, are shown in Fig. 7. The constant excitation of the synchronous motor was 1.58 amperes, the excitation for its operating at practically unity power factor above half load. The resulting power factors are much improved at the generator and receiver ends under light loads. As the load increases, each of these power factors increase more rapidly than in the preceding case, and at full load they reach unity while beyond this point they are a trifle leading. The line drop is not so marked, resulting in better inherent regulation of the system.

The pressure at the generator end remains practically constant after the synchronous motor is thrown on the line. The line current rises gradually, improving the line efficiency by reducing the phase displacement, also improving the transformer efficiencies. Owing to this the transmission efficiency rises quickly and maintains a high value of 82% and over from one-fifth to full load. This bears out the earlier statements of this paper that best results are to be obtained in such a transmission system when the resulting phase displacement is a minimum.

PERFORMANCE WITH OVER-EXCITED SYNCHRONOUS MOTOR LOAD.

The curves of performance under this condition are shown in Fig. 8. The constant excitation of the synchronous motor was 2.58 amperes. The pressure at the generator end does not drop at all when the over-excited synchronous motor is thrown on, having a tendency to rise, due to the phase displacement of its external circuit remaining leading at all loads. This is equivalent, in its effects upon the generator, to over-compounding, producing the so-called "boosting" effect, as shown in Fig. 4, for an equivalent power factor of about 0.90 leading. The secondary

pressure regulation at the receiver end is better than in any previous case, being exceptionally good due to a leading phase displacement which increases with the heavier loads. This has a

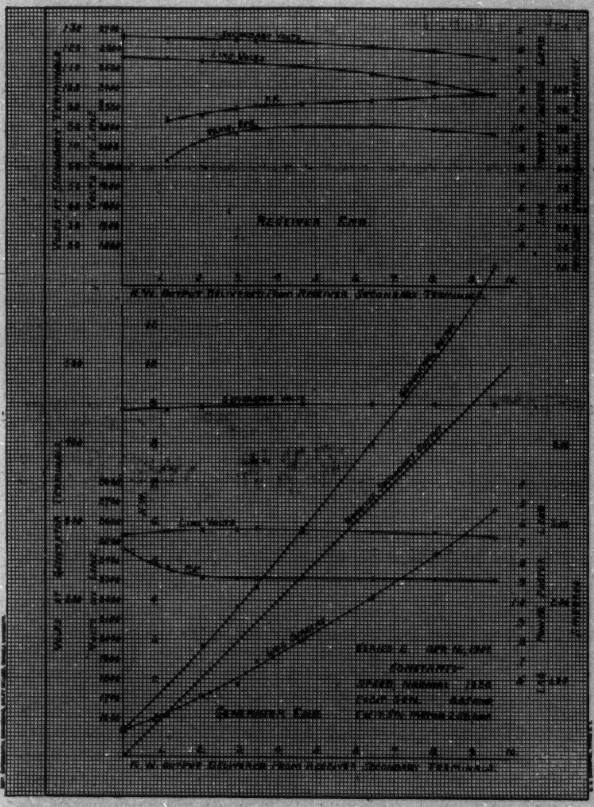

FIG. 8.—Performance with Over-Excited Synchronous Motor Load.

compensating effect upon the secondary receiver voltage which will be noted later.

The transmission efficiency is 80% and over from half to full load. In this case the efficiencies of the transformers are evidently re-

duced at their respective loads by the increased core losses under the higher impressed voltages. Their $I^2R$ losses are also increased for the same respective loads owing to the increasing phase displacement.

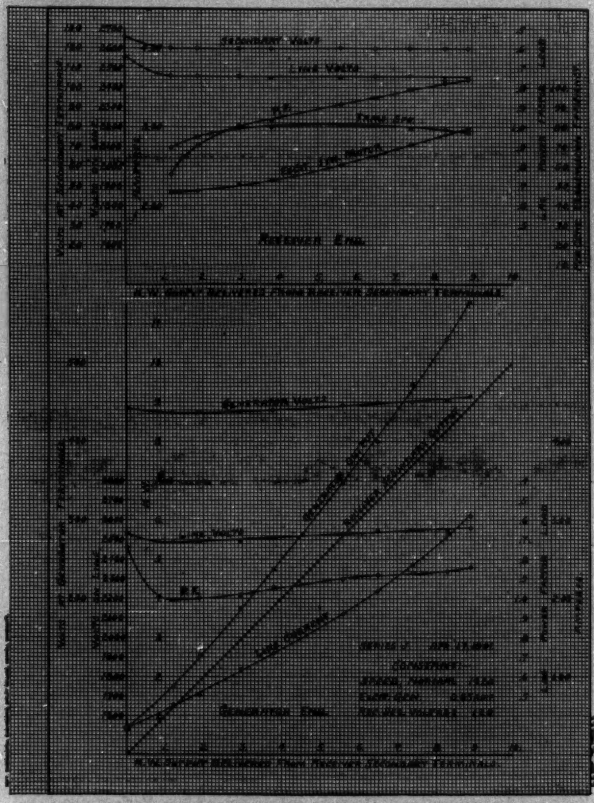

FIG. 9.—Performance with Constant Receiver Secondary Voltage, 120 Volts, and Variable Excitation of Synchronous Motor.

*Constant Receiver Secondary Voltage and Variable Excitation of Synchronous Motor.*—Fig. 9 illustrates the performance where a constant pressure of 120 volts was maintained at the

receiver secondary terminals while the excitation was correspondingly increased with the load. There is increasing leading phase displacement after the small loads are passed. The transmis-

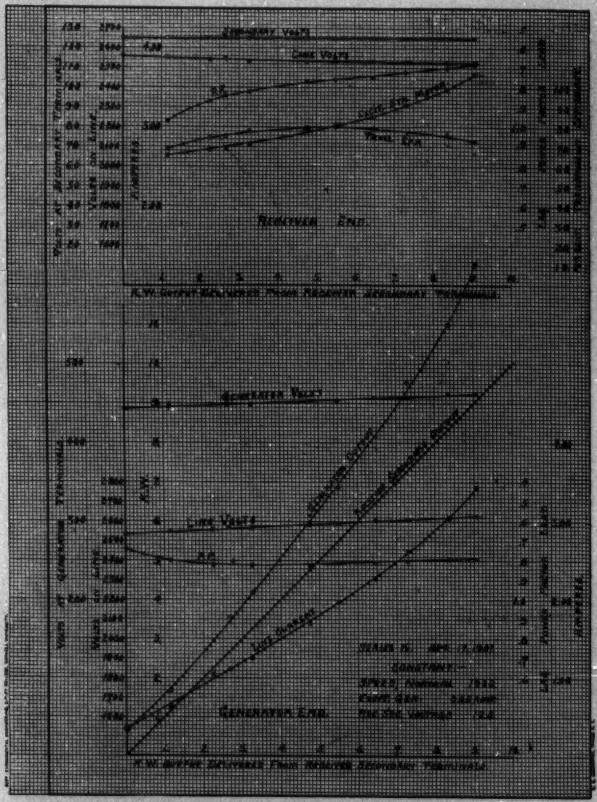

FIG. 10.—Performance with Constant Receiver Secondary Voltage, 125 Volts, and Variable Excitation of Synchronous Motor.

sion efficiency is at and above 80% from one-third to full load. Under similar conditions the receiver secondary voltage was maintained at 125, the no-load pressure, and the results are plotted in Fig. 10. The phase displacement at each end is de-

cidedly leading. Therefore the line current is materially raised, increasing the $I^2R$ losses. Under this condition the transformers were operated at still higher pressures, correspondingly decreasing the efficiency of transmission.

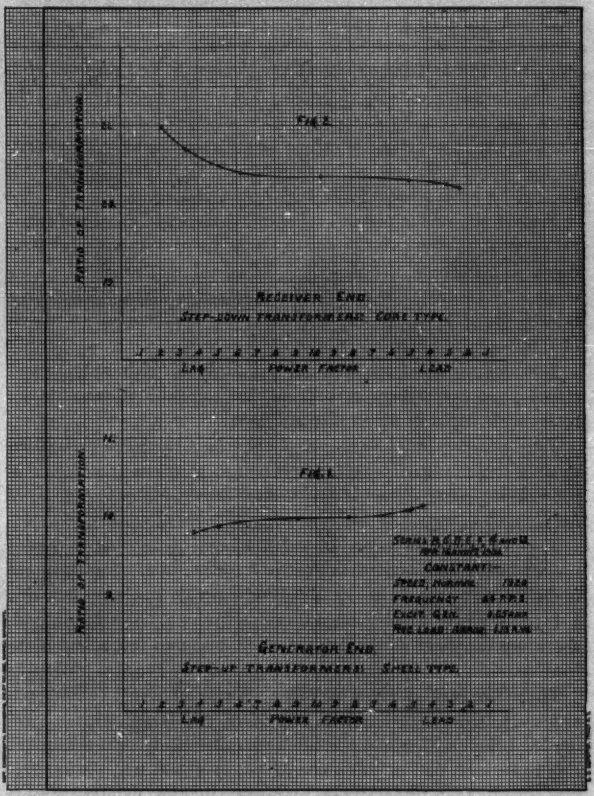


FIG. 11.—Variation of the Transformer Ratios as Function of the Phase Displacement.

*Effect on Generator Voltage by Increasing Synchronous Motor Excitation.*—Under the leading phase displacement of the last

two experiments the pressures at the generator show the characteristic increase earlier noted in Fig. 4.

The leading wattless components of current are comparatively large, and therefore have an appreciable influence upon the performance and regulation of the generator.

*Regulation of Transformers Under Variable Phase Displacement.*—An examination of the transformer ratios as determined by the voltage curves at the generator and receiver ends of the preceding curves of performance, will show that for the small loads especially, the ratio of transformation at each end of the line varies greatly with the phase displacement. This variation of transformer ratios is a function of the phase displacement depending upon whether it is lagging or leading.

Fig. 11 shows the plotted values of these variable transformer ratios, as a function of the power factor for the step-up and step-down transformers respectively. The load was practically constant, at 1.15 K.W., for all of these determinations. The variation in the ratio of the step-down transformers is opposite to that of the step-up transformers.

The following is the general principle for either step-up or step-down transformers, respecting the variation in transformer ratios with variable phase displacement:

*The output voltage increases as the lagging phase displacement decreases, which voltage continues to increase as the displacement passes through unity and becomes more and more leading.*

This variation of transformation ratio will become apparent upon a consideration of the effect of variable phase displacement upon the resultant flux. In any given case this flux is smaller with a lagging phase displacement than with no displacement, and, therefore increases as the displacement becomes more and more leading.

Therefore, with a given primary impressed E.M.F. the secondary E.M.F. will be smaller with a lagging and larger with a leading load, than with a simple non-inductive load. Furthermore, it is to be seen that a difference of phase existing in the secondary circuit of a transformer reappears in the primary circuit somewhat decreased if leading, and slightly increased if lagging.

## Precautions to be Taken with Unloaded Transmission Lines.

Judging from the results of the earlier sets of these experiments it should not be permitted to throw the generator onto an unloaded transmission line where the per cent. resonant rise may be comparatively large. If this should occur it may produce a marked resonant rise in pressure at the receiver end, and moreover increase the ratio of the step-up transformers. It is therefore advisable always to have induction motors or similar inductive reactance connected in the circuit. Furthermore, in designing a transmission line care should be taken to keep very low the ratio of the charging current to the full load power current, so as not to necessitate increasing the size of generating units to supply this charging current.

*Transmission Efficiency.*—The tendency to higher efficiency by increase of the impressed E.M.F., due to any so-called "boosting" throws the current out of phase with its E.M.F. It is evident that when high transmission efficiency is desired it is necessary to keep down the wattless components of current to whatever cause they may be due, quite as much on account of the impairment of transformer efficiency as in the general operation of the system. The three transformers used at each end of the line were of 3 K.W. capacity, of well-known modern types; Fort Wayne for the step-up, and Packard, for the step-down transformers. In almost all instances in these experiments they were operated at somewhat higher voltages than intended. Their $I^2R$ losses were necessarily increased by the extreme range of reactive loads.

*Voltage Regulation.*—The results throughout are given for one phase (A–B) of the three-phase system, which was always balanced. There was comparatively little "hunting" of the synchronous motor under any of the conditions of operation. The transformers had a drop of 3% between no-load and full non-inductive load when operated at their normal voltage. There was also a drop of about 2% in the speed of the alternator between no-load and full-load, due to the increased slip of the induction motor used as a prime mover. After taking these factors into consideration regarding the regulation of the several parts of the system, it is evident that the performance of the transmission system was satisfactory.

*Wave Forms from the Experimental Transmission System.*[1] The instrument used in taking these wave forms was a modification of the Blondel oscillograph. To a small reflecting mirror was attached a very soft Norway iron needle, with a natural period of about one-thousandth of a second. This was suspended vertically by a very fine silk fiber in line of prolongation of horizontal axis of an air-core solenoid of sixty turns of No. 20 (B. & S.) soft single cotton-covered magnet wire. The directive force of the needle was supplied by a pair of permanent steel magnets of horse-shoe form, producing practically a constant field. When an alternating current was passed through the solenoid it produced simultaneous deflection of the needle in frequency, direction and amount proportional to that of the current flowing.

By suitably arranged lenses a beam of light from an arc lamp will be reflected by the mirror upon highly sensitized paper mounted on a rapidly-revolving drum.

The photographic records of the wave forms are necessarily small, from one-half to one inch in amplitude. They were enlarged by throwing onto a screen by a projection lantern and then retraced by hand. Similar recording arrangements have been used with curve tracers. These are necessarily slow and tedious, requiring about half an hour for a complete record of the wave form. The record, therefore, is really a kind of composite photograph, as the wave form meanwhile may have undergone almost an infinite variety of changes. In the modification of the oscillograph as here used the deflections of the needle follow very closely and faithfully any variation in the alternating current, and a record of the wave form is obtained in about one-sixtieth of a second.

Figs. 12 and 13 illustrate the generator and receiver wave forms under typical conditions. Series X is an E. M. F. wave form of the three-phase generator on open circuit. Series Y of Fig. 12 and Series $Y^1$ of Fig. 13 are E. M. F. wave forms taken off the generator and receiver secondary terminals, respectively, under the same conditions of load and simultaneous conditions of operation, with leading phase displacement. These wave forms are very similar,

1. These wave forms were taken by Mr. E. F. Bracken, B.S., in Electrical Engineering, University of Illinois, by the method described in his thesis on "Investigation of the Wave Forms of Alternators and Synchronous Converters," June, 1901.

but the receiver end is distorted more than the one from that of the generator end, as the receiver end power factor was somewhat lower. They show the flattening due to the capacity effect of the leading currents present.

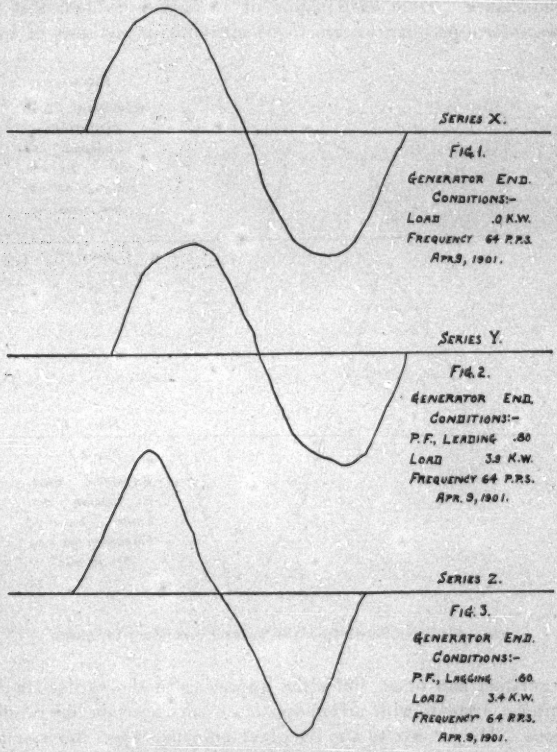


FIG. 12.—Wave Forms from the Generator.

Series z of Fig. 12 and Series $z^1$ of Fig. 13 are E. M. F. wave forms taken off the generator and receiver secondary terminals under the same conditions of load and simultaneous conditions of

operation, but with decided lagging phase displacement. These waves are also similar, but that of the receiver end is more distorted than that of the generator, due to a lower power factor at the generator end. These waves illustrate the effect of lagging currents and show the characteristic peak due to the presence of inductance. From examination of them it is evident that to wave-form peculiarities are to be attributed many cases of bad

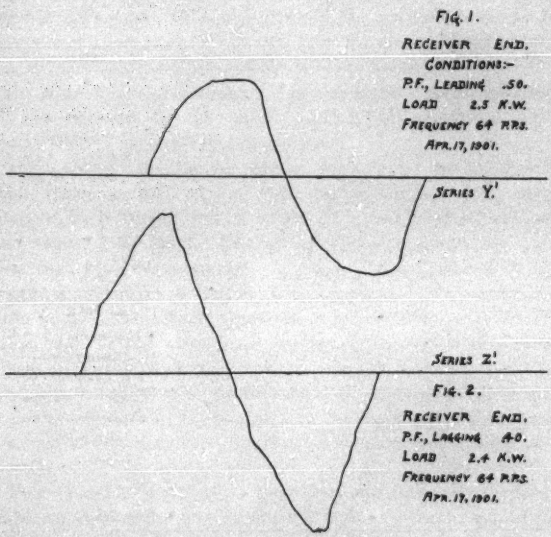


Fig. 13.—Wave Forms from the Receiver Secondary Terminals.

regulation and other difficulties appearing in the earlier transmission systems with mixed apparatus and uncertain line conditions. They illustrate also the great influence upon the E. M. F. waves of the line and generator of the phase relation between the E. M. F. and the current.

If synchronous motors or converters are used, giving wave forms quite different from those of their impressed E. M. F., they will become very unstable in regard to remaining in synchronism.

This dissimilarity of wave forms also necessitates excessive currents, without any regard to the accompanying disadvantages inherent in phase displacement of synchronous machines, and such dissimilarities are purely relative and do not materially concern the question of the intrinsic value of synchronous machines in effecting neutralization of phase displacement.

*A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22nd, 1901.*

[ADVANCE COPY SUBJECT TO REVISION]

# POWER FACTOR INDICATORS.

BY WILLIAM HAND BROWNE, JR.

The introduction of induction motors in factories brings with it a power factor considerably less than unity. Since this requires a larger current for a given power delivered, the total available output of the generating plant is less, and the efficiency of the system is lower than if the load were non-inductive. Further, the wattless component of the current causes increased armature reactions, and consequently seriously affects the regulation of the system.

It therefore may be thought desirable to balance wholly or in part the wattless component of current, due to the induction motors, by the use of synchronous motors or converters, and it then becomes necessary to have some means of knowing when this has been accomplished.

*Methods of Determining Balance.*—One method of judging the conditions of the system, which is used to some extent, is to place an ammeter in the line carrying the current for both induction and synchronous motors. Then to secure a balance, the excitation of the synchronous motor is changed until the line current is a minimum. This method, while simple, is exceedingly crude, and becomes entirely unreliable when the synchronous motor is fairly well loaded. As the power factor of the system approaches unity under these conditions, a comparatively large change in the excitation of the synchronous motor produces little or no apparent change in the ammeter reading. This is because the characteristic v curve of the synchronous motor, *i. e.*, arma-

ture current on a field current base, is quite flat for large loads. The wattless component of current, however, changes very rapidly as will be shown later. The same criticism applies to the use of an indicating wattmeter for securing balance. Here the excitation of the synchronous motor is changed until the volt amperes as found from the ammeter and voltmeter readings are equal to the true watts as indicated by the wattmeter.

To show that both of these methods are unreliable, suppose a small error has been made in reading the ammeter or wattmeter, due to carelessness or to instrumental errors. Fig. 1 illustrates the effect of this error on the wattless component of current, or what

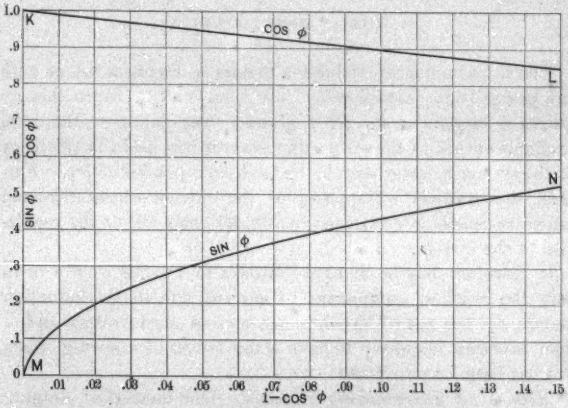


FIG. 1.—Curve showing the rate of change of the sine with the cosine.

is the same thing on sin $\varphi$, the inductance factor; K L represents the power factor for different percentage differences between the true and apparent watts, M N is the corresponding inductance factor curve. For an error of 1 per cent. the inductance factor is .14. For an error of 2 per cent. the wattless component of current is nearly 20 per cent. of the total current. That is to say, when the attendant thinks he has secured a balance, the wattless current may still be a very considerable fraction of the whole, and seriously affect the regulation of the generator.

*Behavior of a Synchronous Motor.*—Fig. 2 shows how a synchronous motor will behave under these conditions. Here a con-

stant applied voltage and a constant true watts input have been assumed, with a variable inductance factor. That is to say, $E I \cos \varphi$ is constant, at 5 kilowatts, represented by the horizontal line FA. (Fig. 2).

The base taken here is $E I \sin \varphi$. The curve B C is $\cos \varphi$ for different values of $E I \sin \varphi$. The curve O D shows the corresponding values of $\sin \varphi$; F G is the armature current. These curves show

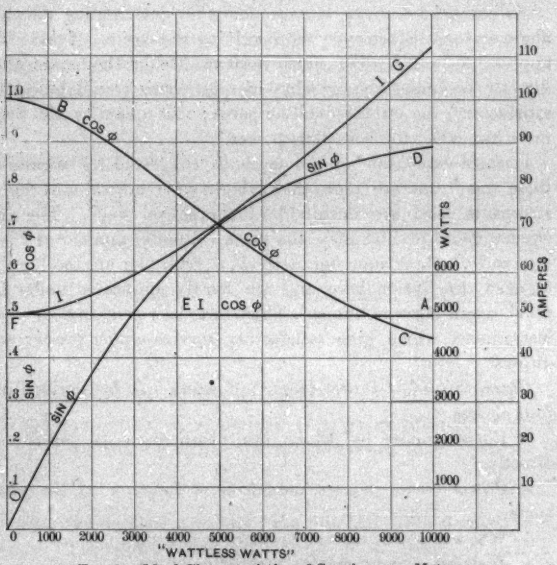


FIG. 2.—Ideal Characteristics of Synchronous Motor.

that as we approach unity power factor $\cos \varphi$ changes slowly and the total current changes slowly, but $\sin \varphi$ (and hence $I \sin \varphi$) changes very rapidly.

The need of an instrument which will indicate accurately the condition of the system as regards balance being evident, it becomes worth while examining the methods and instruments available for such determinations, as well as the quantities to be measured. The phase difference of two waves is usually defined as the displacement in degrees between the points where they

pass, in the same direction, through zero or their maximum values. In alternating current theory, where the two waves are assumed sinusoids and one is the E.M.F. and the other the current, the cosine of the phase angle is called the power factor. It is equal to the ratio of true watts to volt amperes. In practice while we may not have sinusoids, this ratio is still called the power factor and may be considered as the cosine of the phase angle of the equivalent sinusoids.

As pointed out above, measurements for determining the phase angle are unsatisfactory when involving the cosine, if the cosine approaches unity. We must measure either the phase angle directly or indirectly, or what in most cases would be equally satisfactory, the wattless volt amperes; that quantity Mr. Steinmetz has called the "wattless power."

Unfortunately few of the methods suggested for measuring these quantities are more than laboratory methods, and the instruments used are unsuitable for practical work. The split dynamometer of Blakesley, the three voltmeter method of Fleming, and the three ammeter method of Sumpner are too familiar to need description here, and are hardly applicable under the usual operating conditions. There are, however, two or three instruments which give satisfactory service under proper conditions.

*Classification.*—Power factor indicators may be divided into four classes:

1. Phase meters, by which the phase angle is determined directly.

2. Power factor meters, measuring a function of the phase angle.

3. Wattless power meters, measuring $E I \sin \varphi$.

4. Wattless current meters, measuring $I \sin \varphi$.

In the first class we may include, in addition to types to be described below, all forms of oscillographs and curve tracers.

In the second class we may include all instruments measuring $\sin \varphi$ and $\tan \varphi$ as well as $\cos \varphi$.

These classes may be further subdivided, according to the means employed to obtain an indication, into four types:

(*a.*) Electromagnetic, using the force of attraction of electromagnets.

(*b.*) Electro-dynamic, utilizing the reaction between coils carrying currents.

(*c*.) Induction, a rotating magnetic field is set up and used to deflect a disk.

(*d*) Electrolytic, depending upon electrolysis to secure a record.

*Phase Meters.*—The various types of oscillographs and curve tracers are too well known to need description. In general they are laboratory instruments and not applicable to commercial working.

*Tuma's Phase Meter*[1] (1*b*).—Let the pair of coils A B (Fig. 3) carry the current whose phase angle, referred to the E. M. F. is desired.

Within the space between the two, suspended freely, is the movable system C D, consisting of two independent windings connected together mechanically at right angles. Let $\alpha$ be the angle

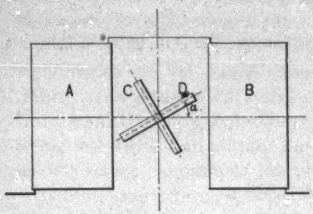


FIG. 3.

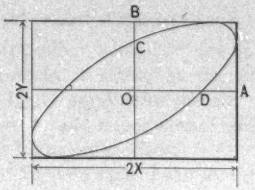


FIG. 4.

which D makes with the axis of A B.

When a current $i_1 = I_1 \sin(\omega t - \varphi)$ passes through A B; this sets up an alternating flux in the space between them equal to

$$N = N_0 \sin(\omega t - \varphi)$$

$N_0$ being the maximum value of the flux and $\omega\, 2\pi$ times the frequency. Through D pass a current in phase with the E. M. F. This will be

$$i_2 = I_2 \sin \omega t$$

1. J. Tuma in *Sitzungsberichte der K. Preussischen Akademie der Wissenschaften*, vol. 106, p. 521, 1897. M. Brieger in *Bulletin de l' Association des Ingenieurs Électriciens*, vol. 11, p. 79, 1899. Aug. J. Bowie, Jr., in *Electrical World and Engineer*, vol. 36, p. 644, 1900. (Mr. Bowie works out the general condition and shows the application to two and three-phase circuits.) H. Armangat in *L'Éclairage Électrique*, vol. 25, p. 339. (Hartmann and Braun instrument.)

And through C pass a current in quadrature with this

$$i_3 = I_3 \sin\left(\omega t - \frac{\pi}{2}\right)$$

The torque set up between A B and D will be

$$T_1 = N i_2 \sin a$$

Between A B and C

$$T_2 = N i_3 \cos a$$

Substituting for N, $i_2$ and $i_3$, the values given above, the effective values are

$$T_1 = \frac{N_0 I_2}{2} \sin a \cos \varphi$$

$$T_2 = \frac{N_0 I_2}{2} \cos a \sin \varphi$$

Since the coil is free to turn, the angle $a$ will be such that

$T_1 = T_2$, then

$$\frac{N_0 I_2}{2} \sin a \cos \varphi = \frac{N_0 I_2}{2} \cos a \sin \varphi$$

$$\tan a :: \tan \varphi$$

The angle $a$ is the phase angle.

*Induction Phase Meters* (1*c*).—If we pass through two coils, concentric but set at an angle with each other, currents which set up equal fluxes differing, however, in phase, a rotating magnetic field of elliptical form will in general be created. If the two coils are inclined at an angle which is the supplement of the phase angle, the resulting field will have a constant value. An armature suitably placed in such a field will cause a ray of light reflected from an attached mirror to travel in a circle. In applying this method it is necessary to have the fluxes of equal value and to change the angle between the coils until the ellipse becomes a circle when the phase angle is read off directly. The instruments of Angelmeyer[1], Korda[1], Hess[1], Rossi[2] and one of Arno[3], make use of this principle.

1. (*a*) "Mesure des Differences de Phase." F. Fontaine in *Bulletin de l' Association des Ingenieurs Electriciens*, Nov. 1899.
2. *L'Eclairage Electrique*, vol 15, pp. 133, 322, 355, 1898.
3. *Ibid*, vol. 21, p. 225, 1899.

*Electrolytic Phase Indicator* (1*d*.)—A very simple device, due to Janet[1], consists of a metallic drum upon which rest two styli of iron. One of these is connected so as to have a difference of potential between it and the drum which is in phase with the current, the other one which is in phase with the E. M. F. On the drum is stretched a sheet of paper which has been soaked in potassium ferrocyanide and ammonium acetate.

When the difference of potential between either stylus and the drum reaches a certain positive value, electrolysis begins and the paper under that stylus turns blue. Now if the drum be turned, each stylus traces a broken blue line on the paper, each blue mark representing part of a positive half wave. The angular distance from the center of one of these short lines and that of the corresponding mark made by the other stylus, expressed in electrical degrees, is the phase angle. This is true only when the two waves have the same form.

*Power Factor Meters* (2).—Two harmonic motions acting at right angles and having the same frequency and amplitude but a difference in phase of 90°, will produce, if acting at the same time, a uniform circular motion. If the amplitudes are not the same, the result is an ellipse, the major and minor axes of which are the respective paths of the two harmonic motions.

If the phase difference is not 90° the two axes of the resulting ellipse do not coincide in direction with the two harmonic motions.

*Puluy's Power Factor Meter* (2*a*).—The principle just described has been made use of by Puluy. Two electro-magnets, through the winding of each of which, one of the currents, the phase difference of which is desired, is passed, act upon two armatures causing them to vibrate in planes normal to each other. A ray of light falling upon a mirror attached to one of these and reflected to a second mirror on the other, and thence to a screen, will describe an ellipse, the shape and position of which is determined by the values of the two currents and the phase difference.

Let $X$ be the amplitude of one vibration and $Y$ that of the other. It is evident that a rectangle, the sides of which are respectively $2X$ and $2Y$, can be circumscribed about this ellipse, Fig. 4. Now when either one of the magnets is acting alone, a

1. See reference (*a*) above.

straight line will be described, $2X$ or $2Y$ in length. The intersection of these lines will be the center of the ellipse.

The co-ordinates of any point on the ellipse, referred to these two lines, will be

$$x = X \sin \omega t \tag{1}$$

$$y = Y \sin (\omega t - \varphi) \tag{2}$$

$\varphi$ being the difference in phase

In equation (1) let $x = 0$, then

$$\omega t = n \pi$$

$n$ being some whole number.

Substituting in (2)

$$y_0 = Y \sin (n \pi - \varphi)$$

$$= \pm Y \sin \varphi = \overline{OC} \text{ (Fig. 4)} \tag{3}$$

Again let $y = 0$ in (2), then

$$\omega t - \varphi = n \pi$$

$$x_0 = X \sin (n \pi + \varphi)$$

$$= \pm X \sin \varphi = \overline{OD} \text{ (Fig. 4)} \tag{4}$$

From (3) and (4) it follows that

$$\sin \varphi = \frac{\overline{OC}}{\overline{OB}} = \frac{\overline{OD}}{\overline{OA}}$$

*Morland's Power Factor Meter.*—In an apparatus described by Mr. Morland[1], the two conductors carrying the two currents pass between the poles of a permanent magnet. Each of these causes a small mirror to vibrate, producing the result just described.

*Claude's Power Factor Meter.*—Claude[2] places the two electro-magnets in direct opposition and causes them to actuate the same armature. Let the maximum flux set up by each coil be $N$. The ray of light reflected from the mirror will under the influence of the flux $N$ oscillate along a path in length $KN$, $K$ being a constant. If both coils were acting and if the currents were in phase, the length of this path would be $2KN$.

1. Apparatus for illustrating change of phase, S. I. Moreland, *Electrical Engineer*, Vol. 26, p. 237, Sept. 8, 1898.

2. See reference (*a*) above.

Call this $d_1$. At any instant the flux due to one coil will be

$$N_1 = N \sin \omega t \qquad (1)$$

That due to the other will be

$$N_2 = N \sin (\omega t - \varphi) \qquad (2)$$

Writing (1)

$$N_1 = N \sin \left[\left(\omega t - \frac{\varphi}{2}\right) + \frac{\varphi}{2}\right]$$

and (2)

$$N_2 = N \sin \left[\left(\omega t - \frac{\varphi}{2}\right) - \frac{\varphi}{2}\right]$$

and taking the sum we have

$$N_1 + N_2 = 2\, N \sin \left(\omega t - \frac{\varphi}{2}\right) \cos \frac{\varphi}{2}$$

and the path to the ray is

$$2\, N K \cos \frac{\varphi}{2}.$$

Call this $d_2$.

Then it follows that

$$\frac{d_2}{d_1} = \cos \frac{\varphi}{2}.$$

It is evident from what has been said above that this method will not be accurate when $\varphi$ approaches zero.

*Rayleigh's Power Factor Meter* (2*a*).—Lord Rayleigh's apparatus[1] for measuring phase angles is somewhat similar to the above. The movable loop is replaced by a soft iron needle and the two coils are placed on opposite sides of this. The equation then becomes

$$d_1 + d_2 + 2 \sqrt{d_1 d_2 \cos \varphi} = d_3$$

The deflections are measured as in a reflecting galvanometer. Mr. Edwin Place[2] gives the results of a great number of experiments made with an instrument of this type. He shows that the angle found in this way is that between the equivalent sine waves. The cosine of this angle, however, is not given by the ratio of true watts to volt amperes, the true power factor.

Tuma[3] describes an instrument similar to the above but with

1. *Philosophical Magazine*, May, 1897.
2. *Electrical World and Engineer*, May 13, 1899, p. 614.
3. *Sitzungsberichte der K. Preussischen Akademie der Wissenschaften* (Berlin) vol. 106, p. 442, 1897.

the coils at right angles. One of these lies in the magnetic meridian.

He shows that, with specially wound coils, if $\varphi$ is the phase angle and $\psi$ the angle between the needle and that coil which lies in the magnetic meridian, then

$$\cos \varphi = \tan 2 \psi.$$

*Dynamometer Types.*—A Siemens electro-dynamometer[1] having two fixed coils may be used for phase angle measurements if the movable system be replaced by a coil closed upon itself and suspended in the plane of the other two.

1. If a current $i_1 = I_1 \sin \omega t$ be passed through one coil, it will set up an E. M. F. in the movable loop

$$e_1 = - M \omega I_1 \cos \omega t.$$

2. When the current $i_2 = I_2 \sin (\omega t - \varphi)$ passes through the second coil it will set up in the movable coil an E. M. F.

$$e_2 = - M \omega I_2 \cos (\omega t - \varphi)$$

$M$ is the mutual inductance and is assumed the same in each case.

3. If the two currents are flowing at the same time, we have in the movable coil

$$e_1 + e_2 = - M \omega [I_1 \cos \omega t + I_2 \cos (\omega \quad - \varphi)]$$

Denoting the angles of torsion necessary to keep the movable coil in its zero position in the three cases by $d_1$, $d_2$ and $d_3$, respectively, and by $t$ the constant of the instrument by $K$, we have

$$K d_1 = M^2 \omega^2 I^2_{1\,\text{eff}}$$

$$K d_2 = M^2 \omega^2 I^2_{2\,\text{eff}}.$$

$$K d_3 = M^2 \omega^2 (I^2_{1\,\text{eff}} + I^2_{2\,\text{eff}} - 2 I_1 I_{2\,\text{eff}} \cos \varphi)$$

Hence

$$d_1 + d_2 - 2 \sqrt{d_1 d_2} \cos \varphi = d_3$$

and the phase angle is deduced from this relation.

1. See reference (*a*) above.

*Arno's "Tangent Phase Meter"* (2*b*).—A second power meter of Arno's[1] consists of a Siemens electro-dynamometer with an additional pair of coils closed upon themselves and fastened together at right angles. The pair as a whole is suspended within the two other coils and may be held in any position by a torsion spring. In Fig. 5 let A and B be the two coils of the dynamometer and C and D the pair of short-circuited loops.

Passing the two currents through A and B respectively, the instrument becomes a wattmeter and we have

$$I_1 I_2 \cos \varphi = k_1 d_1 \qquad (1)$$

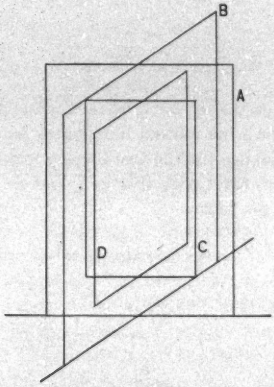


FIG. 5.

where $d_1$ is the angle of torsion required to keep the movable coil in position. $k_1$ is the constant for this system.

Now fix B and pass the current $I_1$ through A, this will set up in C an E. M. F.

$$e_1 = - M I_1 \omega \cos \omega t = M I_1 \omega \sin \left(\omega t - \frac{\pi}{2}\right)$$

This will cause in C a current

$$i_1 = \frac{M_1}{r_1} I_1 \omega \sin \left(\omega t - \frac{\pi}{2}\right)$$

1. *L'Eclairage Electrique*, vol. 12, p. 510; vol. 21, p. 226; vol. 25, p. 484; also reference (*a*) above.

The inductance of the loop is assumed negligible; $r_1$ is the resistance.

This current being in quadrature with that in A will set up no torque.

The current in A will have no inductive effect upon the loop D since they are kept at right angles.

If at the same instant a current $I_2$ is passed through B, we will have at this instant in B

$$i_2 = I_2 \sin(\omega t - \varphi)$$

$$e_2 = M I_2 \omega \sin(\omega t - \frac{\pi}{2} - \varphi)$$

and a current

$$i'_2 = \frac{M}{r} I_2 \omega \sin(\omega t - \frac{\pi}{2} - \varphi)$$

This assumes the same mutual inductance for each pair of coils and the same resistance for the two loops C and D.

This current will react with that in A and set up a torque proportional to their product

$$\frac{M I_1 I_2}{r} \omega \sin \omega t \sin(\omega t - \frac{\pi}{2} - \varphi)$$

The effective value of this torque is

$$\frac{M I_1 I_2}{2 r} \omega \cos\left(\varphi + \frac{\pi}{2}\right) = \frac{M I_1 I_2}{2 r} \omega \sin \varphi$$

It is evident that the couple existing between B and C will have the same value but have an opposite sign, since the current in C being in quadrature with that in A will be less than 90° behind B, while that in D will be more than 90° behind A.

The resulting torque of the system is proportional to $I_1 I_2 \sin \varphi$ and may be written

$$I_1 I_2 \sin = k_2 d_2 \qquad (2)$$

where $k_2$ is a constant and $d_2$ the angle of torsion.

Dividing (2) by (1) we have

$$\frac{k_1 d_1}{k_2 d_2} = k \frac{d_1}{d_2} = \tan \varphi$$

giving the phase angle in terms of its tangent.

*Breitfield's Method* (2*b*).—Mr. C. Breitfield[1] has suggested an application of an ordinary wattmeter for measuring the power factor of a three-phase system. The current coil is placed in one line and one end of the pressure coil also connected to this line. The other end is first connected to the second line and then to the third. In the first case we have the deflection

$$d_1 = E\,I \cos(\varphi - 30°)$$

In the second

$$d_2 = E\,I \cos(\varphi + 30°)$$

From these equations we have

$$d_1 - d_2 = E\,I \sin\varphi \sin 30°$$

$$d_1 + d_2 = E\,I \cos\varphi \cos 30°$$

Hence

$$\tan\varphi = \sqrt{3}\left[\frac{d_1 - d_2}{d_1 + d_2}\right]$$

*General Electric Company's Instrument* (2*b*).—The well-known fact that the ratio of the readings of the two wattmeters used to measure the power of a three-phase system changes with the power factor and is unity when the power factor is unity, has been made use of by the General Electric Company to indicate the power factor. The instrument[2] is simply two wattmeters of the dynamometer type, the movable coils of which are attached to the same spindle. The instrument deflects to the right or left according as the current lags or leads, and stands at zero when the system is balanced and the power factor unity.

*Ferraris' Power Factor Meter* (2*c*.).—Ferraris[3] combines two harmonic fields, producing a rotating field of elliptical form. Within this field is suspended a short-circuited coil which can be held in any position, by a torsion spring, as is the movable coil of a Siemens' dynamometer. The force required and therefore the angle through which the spring must be turned, to hold the coil in any position is proportional to the square of the intensity of the flux in that direction. Points can thus be determined and

1. *Electrotechnische Zeitschrift*, vol. 20, p. 120, 1899.
2. *Electrical World and Engineer*, vol. 37, p. 688, April 27, 1901.
3. See reference (*a*) above.

the ellipse plotted and the sine of the phase angle deduced as above. (See Puluy's Method, page 481.)

*Power Factor Indicators* (*3*).—In the methods described above, the object sought was the determination of the phase angle. But few of these are applicable under the usual operating conditions. We might mention as useful forms, those of Tuma and the General Electric Co. In most cases, however, we are more concerned with the magnitude of the wattless component of current than with the power factor. We care less about the decrease in the total output than about the poor regulation caused by inductive loads. Instruments which will indicate the wattless current, or rather the wattless volt amperes are easily made in commercial form.

"*Wattless Wattmeters.*" *Dynamometer Type* (*3b*).—A Siemens dynamometer becomes a wattmeter indicating $E\,I \cos \varphi$ when the current is passed through one coil and a current proportional to and in phase with the E. M. F. through the other.

If the current in the pressure coil be in quadrature with the E. M. F. the instrument indicates $E\,I \sin \varphi$, the wattless volt amperes.

This is easily done with a two-phase system. With a single-phase system it is necessary to place a proper condenser or inductive reactance in series with the pressure coil.

"*Wattless Wattmeters.*" *Induction Type* (*3c*). *Dobrowolski's Power Factor Indicator*[1].—In a fully compensated induction meter the shunt flux is in quadrature with the series flux, the result of the two being a rotating or shifting field. If the shunt flux be brought into phase with the series flux an alternating field only will be set up as long as the current and E. M. F. are in phase. If, however, the current lags, the field will rotate in one direction. If it leads, the field will rotate in the opposite direction. The torque developed on a disk placed in this field is, in either case proportional to $E\,I \sin \varphi$, the wattless volt amperes. This is the principle of Dobrowolski's apparatus.

The movable disk is held in its zero position by a spring when the wattless volt amperes are zero, but deflects one way or the other, when the current is out of phase, an amount proportional to $EI \sin \varphi$.

Any induction wattmeter can be used in this way provided the flux through the pressure coil be brought into phase with the E. M. F.

1. U. S. Patent No. 549,449, 1895.

*Wattless Current Meters* (*4*).—The Allegemeine Electricitäts Gesellschaft make an instrument[1] which indicates the wattless current. This is really an induction wattmeter having the shunt flux in phase with the E. M. F. and indicates therefore only when there is a phase difference. As an instrument of this type indicates $EI \sin \varphi$, it is presumed that this meter is graduated to read

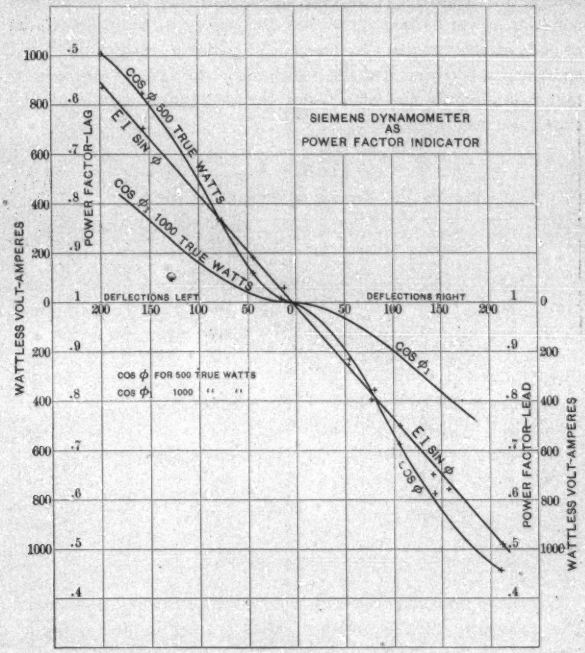


FIG. 6.

$I \sin \varphi$ at normal voltage, and should properly come under "wattless wattmeters" (*3c.*)

## BEHAVIOR OF POWER FACTOR INDICATORS.

*The Siemens Electro-dynamometer.*—The following set of curves (Fig. 6) were taken with a Siemens dynamometer, the

1. *L'Eclairage Electrique*, vol. 35, p. 389.

movable coil of which was in series with a capacity of 3.5 microfarads. The values of $\cos\varphi$, $\sin\varphi$ and $EI\sin\varphi$ plotted have been computed from ammeter, voltmeter and wattmeter readings given in Table I.

$EI\sin\varphi$ is a straight line and is plotted above and below the axis to indicate lagging and leading currents respectively. The base is the deflection in degrees. These curves were taken for a constant power delivered, of 500 true watts. The displacement of current was obtained by means of a phasing transformer. For comparison between $EI\sin\varphi$ and $\cos\varphi$ the axis of abscissæ is taken as unity for the latter, and the decreasing values plotted above and below this.

TABLE. I.

Siemens Dynamometer as Power Factor Indicator.

| Amp. $I$ | Volts $E$ | Watts $EI\cos\phi$ | Deflection. | Direction. | Phase | Apparent watts $EI$ | Power factors $\cos\varphi$ | Inductance factors $\sin\phi$ | $EI\sin\phi$ |
|---|---|---|---|---|---|---|---|---|---|
| 1.15 | 108 | 500 | 213 | Right | Lead | 1096 | .456 | .889 | 975 |
| 8.4 | 108 | 500 | 158 | " | " | 907 | .552 | .834 | 755 |
| 7.58 | 107.9 | 500 | 141 | " | " | 818 | .611 | .791 | 647 |
| 6.51 | 108 | 500 | 106 | " | " | 703 | .711 | .703 | 494 |
| 5.63 | 107.8 | 500 | 78 | " | " | 607 | .823 | .568 | 294 |
| 5.25 | 107.8 | 500 | 53 | " | " | 516 | .884 | .467 | 241 |
| 4.78 | 105.5 | 500 | 13 | Left | Lag | 504 | .992 | .126 | 63 |
| 5.05 | 105.7 | 500 | 44 | " | " | 533 | .938 | .346 | 185 |
| 5.67 | 106.1 | 500 | 76 | " | " | 602 | .831 | .555 | 334 |
| 8.17 | 106 | 500 | 155 | " | " | 866 | .577 | .817 | 707 |
| 9.61 | 105.9 | 500 | 197 | " | " | 1007 | .497 | .867 | 873 |

Note.—Pressure coil in series with 3.5 microfarads capacity.

We notice first that these lines do not pass through the origin. The resistance of the pressure coil is not negligible, as the instrument shows a slight deflection at unity power factor. The curves show very clearly that a slight change in the power factor when near unity caused a comparatively large change in the value of $EI\sin\varphi$.

This fact is very striking when working with the instrument. It may be made to deflect considerably to the right or left without producing any appreciable change in the reading of the Weston wattmeter, the current and voltage remaining constant the while.

Power factors for larger power delivered, lie below the one just considered and hence are still flatter when approaching unity. One for 1,000 true watts has been plotted from calculated values only. It shows that it would be practically impossible to say from ammeter, voltmeter and wattmeter readings alone, when the current was in phase with the E. M. F. With the power factor indicator, however, there would be no difficulty in getting an almost exact adjustment.

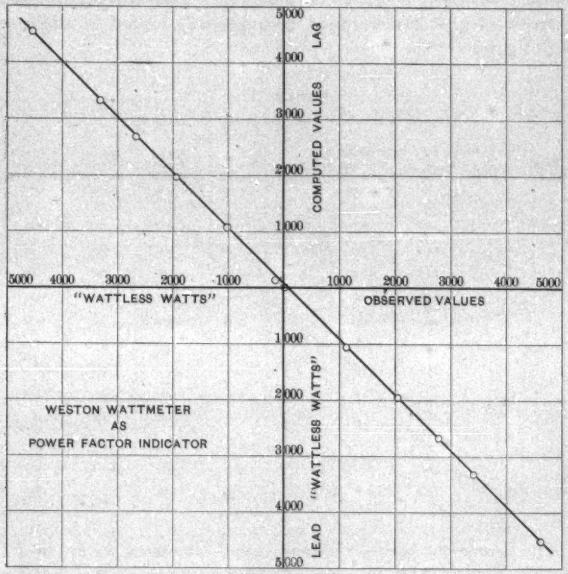


FIG. 7.

*Weston Wattmeter as Power Factor Indicator.*—In Fig. 7 is given the characteristic of a Weston wattmeter of 150 volts, 50 amperes capacity, used on a two-phase system in the manner described above. The characteristic is a straight line, but does not pass through the origin.

This may be due either to the slight inductance of the pressure coil, or to a slight change in the phase angle between the impressed E. M. F.'s or to both.

The method of calibrating consisted in connecting the pressure coils of the power factor indicator and wattmeter respectively to the two primary windings of a two-phase induction motor, used as a phasing transformer. The current coils of the meters were in series and connected to the movable secondary. As the secondary is shifted, the load is partially shifted from one phase of the primary winding to the other. This doubtless caused a slight change in the phase angle between the E. M. F.'s at the motor terminals. The motor used was rated at two horse-power. The supply was drawn from two 4 K. W. transformers, both partially loaded in addition with lights.

TABLE II.

Weston Wattmeters as Power Factor Indicator.

| True Watts. | Voltage. | Amperes. | Wattless volt amperes observed. | Phase relation. | Volt-amperes. | Power factor. | Inductance factor computed. | Wattless volt-amperes computed. |
|---|---|---|---|---|---|---|---|---|
| 1970 | 111.5 | 44.4 | 4530 | Lag | 4950 | .398 | .917 | 4540 |
| " | " | 34.7 | 3325 | " | 3870 | .509 | .860 | 3330 |
| " | " | 29.8 | 2690 | " | 3340 | .590 | .807 | 2690 |
| " | " | 25.0 | 1950 | " | 2790 | .706 | .708 | 1975 |
| " | " | 20.1 | 1050 | " | 2240 | .879 | .427 | 1070 |
| " | " | 17.7 | 180 | " | 1975 | .997 | .071 | 140 |
| " | " | 17.65 | 0 | — | 1970 | 1.0 | .0 | 0 |
| " | " | 20.1 | 1130 | Lead | 2240 | .879 | .477 | 1070 |
| " | " | 25.0 | 2050 | " | 2790 | .706 | .708 | 1975 |
| " | " | 29.8 | 2785 | " | 3340 | .590 | .807 | 2690 |
| " | " | 34.7 | 3420 | " | 3870 | .509 | .860 | 3330 |
| " | " | 44.4 | 4610 | " | 4950 | .398 | .917 | 4540 |

The agreement between observed and calculated values of $EI \sin \varphi$ is good. Table II gives observed and computed values for this instrument.

*Induction Meters.*—In Fig. 8 are shown a set of curves obtained from a Shallenberger integrating wattmeter used as a power factor indicator. The instrument is a 500-volt, 10-ampere meter of the older type (1898). The reactive coil was replaced by a non-inductive resistance of 2,000 ohms. In series with this was a capacity of 3 mf., this being found to balance the inductance of the shunt coil at a frequency of 60 cycles. In this case the instrument was used as a recording meter. The curves plotted are

$EI$ sin $\varphi$, cos $\varphi$ and $\varphi$, all on a revolutions per minute base, for a delivered power of 500 true watts. Table III gives the instrumental readings and computed values for these curves.

Fig. 9 shows the results from the same meter under somewhat different conditions. Here the recording train was removed to lessen the friction, and a light steel spring attached to the spindle of the revolving disk. A pointer attached to the disk

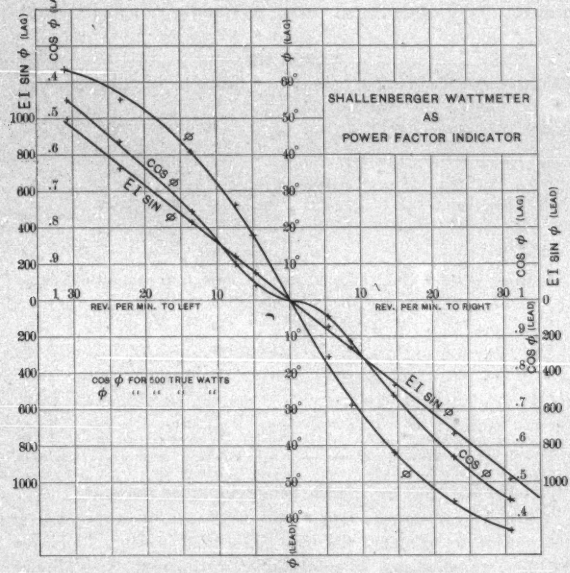


Fig. 8.

passed over a scale marked in degrees. The curves plotted are, as before, $EI$ sin $\varphi$, cos $\varphi$ and $\varphi$, for a delivered power of 500 true watts. The base is degrees deflection. It will be noticed that from 20° lag to 20° lead the deflection is almost directly proportional to the phase angle. The flattening of the curve for cos $\varphi$ is very marked. This instrument was even more sensitive than the dynamometer and besides was dead beat, as the damping

magnets were left in. Table IV gives the instrumental readings and computed values for these curves.

*Application of Power Factor Indicator.*—To illustrate the application of a power factor indicator, the Weston wattmeter mentioned above was used to measure the wattless volt amperes taken by a General Electric 7½-kilowatt, 125-volt, four-pole, synchronous converter for different values of field current. The converter was run on a two-phase system at constant input. The supply was drawn from two Westinghouse 7½-kilowatt transformers, O. D. type, fitted with a Hartford regulator. The

TABLE III.

Shallenberger Wattmeter as Power Factor Indicator. 10 amp. 400 volts.

| No. | Amp. | Volts. | Watts | r.p.m. | Direction. | Phase. | Apparent watts $EI$ | Power factor $\cos\phi$ | Phase Angle $\phi$ | Inductance factor $\sin\phi$ | $EI\sin\phi$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10.01 | 111.3 | 505 | 30.8 | Left | Lagging | 1114 | .449 | 63° — 10′ | .898 | 996 |
| 2 | 8 | 111.5 | 505 | 23.4 | " | " | 891 | .567 | 55—27 | .824 | 734 |
| 3 | 6 | 111.5 | 505 | 13.45 | " | " | 669 | .756 | 40—53 | .655 | 438 |
| 4 | 5.07 | 111.0 | 505 | 7.45 | " | " | 563 | .898 | 26—06 | .440 | 248 |
| 5 | 4.78 | 110.3 | 505 | 4.68 | " | " | 527 | .954 | 17—26 | .300 | 158 |
| 6 | 4.5 | 111.9 | 505 | 0 | — | — | 504 | 1.00 | 0 | 0 | 0 |
| 7 | 4.58 | 114.5 | 505 | 5.29 | Right | Leading | 525 | .962 | 15—50 | .273 | 143 |
| 8 | 5.00 | 114.3 | 504 | 8.7 | " | " | 572 | .881 | 28—14 | .473 | 270 |
| 9 | 6.09 | 112.2 | 505 | 14.6 | " | " | 684 | .738 | 42—26 | .675 | 462 |
| 10 | 8.0 | 111.3 | 505 | 22.8 | " | " | 890 | .567 | 55—28 | .824 | 733 |
| 11 | 10.0 | 111.2 | 505 | 30.6 | " | " | 1112 | .454 | 63—00 | .891 | 992 |

Note.—Impedance coil cut out and shunt coil in series with three microfarads and 2,000 ohms.

output was absorbed by a lamp bank and water rheostat.

In Fig. 10, armature, current and wattless volt amperes have been plotted as ordinates, the base being field current. The input was 3½ K. W. per phase. The flatness of the current curve alluded to above is quite noticeable here. The characteristic for wattless volt amperes is plotted above and below the axis of abscissæ to indicate lagging and leading currents respectively.

The instruments were quite steady, a condition indicating but little hunting of the armature, although there were no devices on the machine to prevent this phenomenon. The power factor indicator, although exactly like the wattmeter, was even steadier than the latter. There was no difficulty in setting the indicator to read any desired value by adjusting the field current.

It was stated[1] at a recent meeting of the National Electric Light Association, during the discussion of a paper on synchronous converters, that it was practically impossible to operate a synchronous motor or converter at unity power factor. The reasons given were hunting of the armature and dissimilar E. M. F. waves of motor and generator. In the above experiment it was found that the power factor indicator could be set at zero and under these conditions the true watts and the volt amperes were equal. This condition would seem to be that of practically unity power factor.

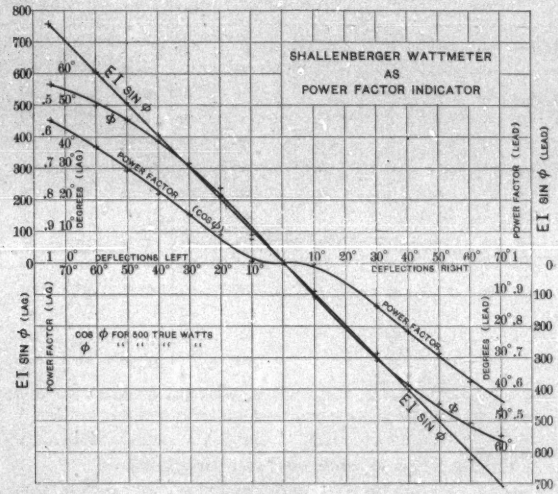


FIG. 9.

A number of power factor curves of synchronous converters have been published recently in which the current passes from lag to lead without the power factor passing through unity. Even if it were impossible to hold the power factor at unity, it must pass through this value as it swings across the line.

In Fig. 11 are plotted, on an excitation base, curves of power factor from wattmeter readings and inductance factor from the

1. *Western Electrician*, Feb. 9, 1901.

"wattless wattmeter" readings. In addition there have been plotted two curves obtained by assuming these values to be cosines and sines of phase angles and the corresponding values of sines and cosines taken from tables and plotted on the same base. These deduced values do not agree at all with the observed ones. The discrepancy is greater for leading than lagging currents. This discrepancy, as has been pointed out by Mr. Steinmetz[1], is

TABLE IV.

Shallenberger Wattmeter as Power Factor Indicator.

| No. | Amperes. | Volts. | True watts. | Degrees deflection. | Direction. | Phase | Apparent watts. | cos $\phi$ | $\phi$ | sin $\phi$ | $EI \sin \phi$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8.29 | 110. | 500 | 75° | Left | Lag. | 911 | .549 | 56°—42′ | .836 | 761 |
| 2 | 7.27 | 108.5 | 500 | 60 | " | " | 788 | .634 | 50—39 | .773 | 608 |
| 3 | 6.54 | 109. | 500 | 50 | " | " | 712 | .702 | 45—35 | .712 | 507 |
| 4 | 5.85 | 110.5 | 500 | 40 | " | " | 646 | .774 | 39—17 | .633 | 409 |
| 5 | 5.41 | 109.2 | 500 | 30 | " | " | 590 | .848 | 32—00 | .530 | 313 |
| 6 | 4.94 | 109.9 | 500 | 20 | " | " | 543 | .921 | 22—56 | .390 | 212 |
| 7 | 4.57 | 111.1 | 500 | 10 | " | " | 507 | .987 | 9—04 | .158 | 80 |
| 8 | 4.59 | 108.4 | 500 | 0 | — | — | 498 | 1. | 0. | 0 | 0 |
| 9 | 4.67 | 109. | 500 | 10 | Right | Lead | 509 | .982 | 10—53 | .189 | 96 |
| 10 | 5.35 | 108. | 500 | 30 | " | " | 578 | .865 | 30—07 | .502 | 290 |
| 11 | 5.87 | 109.4 | 500 | 40 | " | " | 642 | .78 | 38—44 | .626 | 402 |
| 12 | 6.45 | 109.7 | 500 | 50 | " | " | 707 | .708 | 45—05 | .706 | 498 |
| 13 | 7.44 | 107.4 | 500 | 60 | " | " | 799 | .626 | 51—13 | .779 | 623 |
| 14 | 8.16 | 108.7 | 500 | 70 | " | " | 886 | .564 | 55—40 | .826 | 732 |

Note.—Impedance coil removed and shunt coil in series with three microfarads and 2,000 ohms non-inductive resistance. Recording gear removed and light torsion spring attached to disk.

due to the distortion of the E. M. F. and current waves.

Table V gives observed and computed values for these curves.

*Conclusions.*—It would seem from the above that there is a decided need of an accurate power factor indicator in all large installations, but especially in those in which induction and synchronous motors are used together. This method of operation has been adopted by the Deering Harvester Company, where adjustment of the exciting current of the synchronous machine is

1. Symbolic Representation of General Alternating Waves and of Double-Frequency Products. C. P. Steinmetz, TRANSACTIONS, vol. 16, p. 289, 1899.

made by means of a wattmeter, and at Butte, Montana[1], where adjustment is made from ammeter readings. The advisability of adopting this composite system is not in question here. We are considering merely the best method of attaining the end sought.

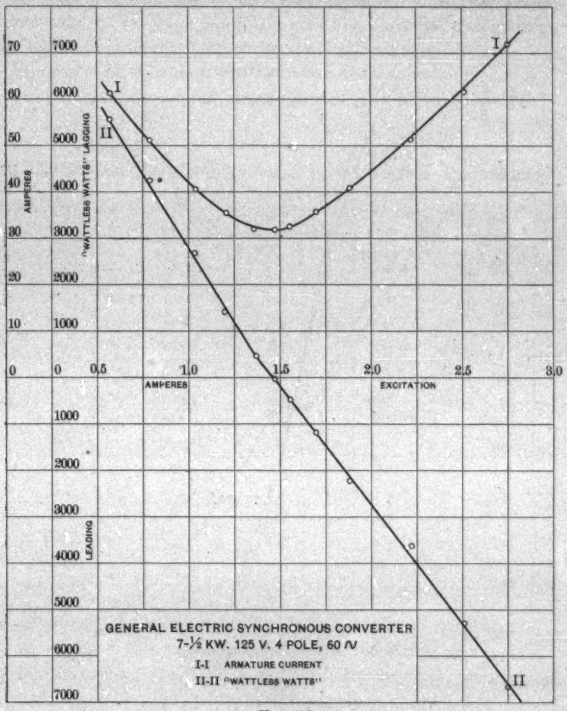


FIG. 10.

For accurate adjusting of the system the indications of the instrument should depend upon the values of $\varphi$ or $\sin \varphi$ and not upon $\cos \varphi$.

Instruments of the dynamometer or the induction type seem more suitable for operating conditions. If the meter be of the

1. Elec. Lt. & Power at Butte, Mont. J. R. Cravath, Elec. W. & E., vol. 37, p. 149, Jan. 26, 1901.

dynamometer type the resistance of the pressure coil must be negligible if it is to be used on a single-phase system, as the cur-

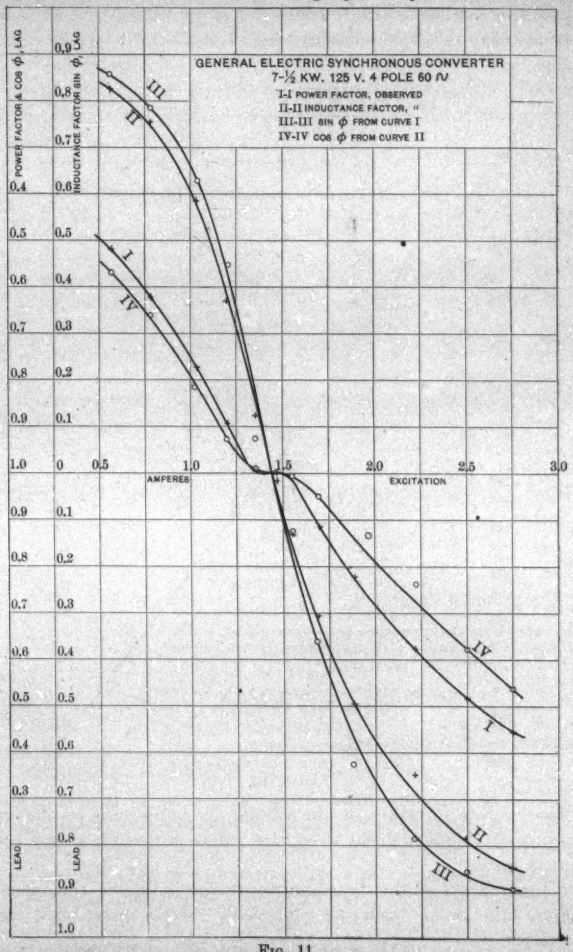


FIG. 11.

rent in this coil must be in quadrature with the E. M. F.

If the meter is to be used on a two or a three-phase system,

the inductance of the pressure coil must be negligibly small, and meter connected in one of the methods described above. In this case care must be taken that the loads on the different phases be kept equal. In a two-phase system, unbalancing the phases will shift the E. M. F.'s relatively to each other. In a three-phase system, since the meters used are really wattmeters, unbalancing the phases will vitiate the indications of the instrument.

If the meter be of the induction type the inductance of the pressure coil must be negligible, since not only is it undesirable

TABLE V.

General Electric Synchronous Converter. 7½ K.W., 125 V., 4-pole, 60 ~, 2-phase. Input 3.5 K.W. per phase.

| Wattless kilo-volt amperes. | Amperes armature current. | Voltage at brushes. | Amperes field current. | Phase relation. | Kilovolt amperes | Power factor. | Inductance factor. | $\sin\phi$ computed from power factor. | $\cos\phi$ computed from inductance factor. |
|---|---|---|---|---|---|---|---|---|---|
| 5.55 | 61.6 | 109.9 | 0.57 | Lag | 6 76 | .518 | 822 | .855 | .569 |
| 4.23 | 51.3 | 110.0 | 0.78 | " | 5.64 | .621 | 750 | .784 | .661 |
| 2.62 | 40.9 | 109.9 | 1.03 | " | 4.5 | .778 | .583 | .628 | .812 |
| 1 45 | 35 7 | 109.7 | 1.2 | " | 3.91 | .895 | .371 | .446 | .929 |
| 0.45 | 32 0 | 109.8 | 1.36 | " | 3.51 | .997 | .128 | .077 | .992 |
| — 0.05 | 31.9 | 109.8 | 1.47 | Lead | 3.50 | 1.0 | .014 | .0 | .999 |
| — 0.45 | 32.1 | 110.0 | 1.55 | " | 3.53 | 992 | .128 | .126 | .992 |
| — 1.20 | 35.7 | 110.4 | 1.69 | " | 3.94 | .888 | .306 | .460 | .952 |
| — 2.22 | 40.9 | 109.8 | 1.88 | " | 4.49 | .779 | .495 | .627 | .869 |
| — 3 65 | 51.3 | 110.0 | 2.22 | " | 5.64 | .621 | .648 | .784 | .762 |
| — 5 30 | 61.6 | 110.2 | 2.5 | " | 6.78 | .516 | .782 | .857 | .623 |
| — 6 65 | 71.9 | 101.8 | 2.75 | " | 7 89 | .444 | .844 | .896 | .536 |

to use condensers to compensate for this, both from their bulkiness and expense, but the presence of any reactance makes the deflection dependent upon the frequency. An attempt was made to improve upon the induction meter described above by removing the three-legged stampings of iron upon which the pressure coil was wound. The inductance was still too large for satisfactory working and as the condensers in the laboratory were not sufficient to compensate for this, it was necessary, to make up for this lack of capacity and to avoid the use of iron, to add an auxiliary inductance wound on a wooden bobbin. The instrument thus modified was found to be so sensitive to slight changes in frequency that it was impossible to use it with any degree of

satisfaction in the laboratory. Any change of load on the prime mover would so change the reading of the instrument as to make its indications extremely unreliable.

Dobrowolski shows, in the reference given above, the application of his instrument for automatically adjusting the excitation of the synchronous machine so as to keep the power factor at unity at all times.

The use of an instrument of this kind emphasizes the fact that, when induction motors are used alone, the inductance factor is always a large percentage of the power factor. For instance, when the power factor is .85 the inductance factor, assuming sinusoidal waves, is nearly 62% of this. That is, for every kilowatt used by the motor, 620 "wattless watts" are, so to speak, borrowed. It would seem but fair that those who use induction motors should at least pay rental for the wattless volt amperes required. It is true this does not represent energy consumed, but it does, in a sense, represent energy borrowed and returned and the station must have sufficient capacity in generators to meet all such calls for loans.

The additional charge could be taken care of by over-compensating integrating wattmeters of the induction type, as suggested by Mr. Benischke. They would then read high on lagging reactive loads and low on leading reactive loads. This would put a premium on the use of synchronous motors as they, if not too greatly over-excited, help out in the regulation of the plant. The induction motor has so many points in its favor it can well afford to pay for what it needs—a large wattless component of current.

*A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22nd, 1901.*

[ADVANCE COPY—SUBJECT TO REVISION.]

# ELEMENTS OF DESIGN PARTICULARLY PERTAINING TO LONG DISTANCE TRANSMISSION.

BY F. A. C. PERRINE.

The popular admiration of a big thing is not unwarranted from an engineering standpoint. The mere bigness of an engineering problem oftentimes introduces new elements into the solution. Ordinary methods of handling materials become impracticable when the size of the work passes that usually undertaken, stresses heretofore unconsidered become important and introduce great difficulties by reason of the extra precautions necessary in their consideration. The electrical transmission problem is no exception to this general rule, for, were it always necessary to consider all the phenomena involved in every electrical transmission problem, the solution of a great long distance problem would be the same as that of the smallest piece of work, since the introduction of larger figures in an equation introduces no difficulties in the solution. But this is not the case. In short distance work there are less terms in the equation than there are in long distance work, and in handling extremely high potentials we must consider not only the electrical factors of safety, but also mechanical factors of safety, for the reason that good insulations are never materials of great strength, and can be relied upon for their mechanical properties only when the mechanical strains are unimportant in comparison with the side of the insulating pieces employed. Were it not for these considerations it might be more expensive to transmit 10,000 K. W. one hundred miles than to transmit the same amount of power a

single mile, but to the competent electrician not more difficult. All of the phenomena which must be considered in short distance work are introduced into long distance problems in the same form. The difficulty in long distance transmission problems lies in the introduction of phenomena which are not new, but which, as has already been said, are important only in work of the latter class.

No new interpretation of Ohm's law becomes necessary as resistance rises and our lines become long, and the loss of energy over a wire of a given resistance due to its resistance remains unchanged, though, of course, we must always give due consideration to the false resistance effects that may be introduced by the size of the conductors employed. In the earlier transmission lines where distances of from 10 to 20 miles were considered, and voltages from five to 20,000 volts employed, investors hesitated to buy the amount of conductor material necessary to reduce the losses, to amounts of the order employed in short distance work, and in consequence with resistance losses amounting to from 26 to 30%. While the regulation problems were of great difficulty, the wires were small, and the false resistance or so-called "skin effects" unnoticed. But with the continued success that has attended the introduction of long distance lines, the investors who have had sufficient courage to approach the problem of transmitting great powers over great distances have felt it unnecessary to restrict the engineers in the quantity of material, and, in consequence, the most recent systems have employed conductors of such a size as to necessitate the consideration of these phenomena a matter of no great difficulty to be sure, and one which only determines the limit of size of a single line. This problem has been further simplified by an agreement between the engineer and the investor that for permanence of supply duplicate lines seem almost necessary.

Perhaps the most important question to face in the long distance transmission is that of regulation. In working short lines, even with alternating currents, the regulation as the load changes is determined almost completely by the resistance effect. Occasionally when heavier currents are employed the self-inductive effects have to be considered, and generally the mutual induction from and to other lines becomes an important factor, though in determining the question of regulation the capacity effects are entirely unimportant.

Whether the lines are long or short, the current small or great, self induction, mutual induction, and capacity, as well as resistance are ever present as phenomena. But while with short lines the capacity is the least important of these phonomena and is so unimportant as to be absolutely unconsidered, with long distance lines it becomes the predominant factor. The importance of the capacity factor increases with the quantity of the charging current. This quantity, of course, depends upon the capacity of the circuit, the voltage employed, and the periodicity. A long distance line would be commercially unsuccessful were not the highest possible voltages used, and the usefulness of the current rises, within certain limits, with the periodicity. Accordingly, in long distance lines where periodicities are employed from which incandescent and arc lighting may be directly performed, high voltages entail very great charging currents to such an extent that in a line of 100 miles in length, operating at a voltage of 50 or 60,000 volts and a periodicity of 50, the charging current amounts to something in excess of 2,000 kilovolt amperes, and employs such a proportion of the capacity at the station for charging the idle lines as to make the introduction of units smaller than 2,000 K. W. inadvisable, and renders commercially impracticable the transmission of powers less than about 3,000 K. W., unless the capacity effect be neutralized by the use of reactive coils.

Following the capacity in important effect on regulation is the self-induction. While the mutual induction may become another factor, it is only considered in order to be eliminated by transposition of the wires, all of which leaves of the three final factors involved, the resistance of the line in the most unimportant place, though in short distance work it is the determining factor. The elimination of mutual induction by transposition is generally an exceedingly simple problem, for the reason that the lines are almost invariably few in number and follow each other with constant load for considerable distances, allowing the transpositions to be readily made at or between poles where every facility is offered for making them simply. The self-inductive effects, while important, and increased by the length of the lines, are nevertheless comparatively small in reference to the total amount of power transmitted, for the reason that the high voltages decrease the quantity of current, and so far as the line is concerned, the self-induction is rather a benefit than a detriment,

since the leading current due to capacity is relatively so large. Self-induction does indeed influence the regulation as the load changes and the more nearly the line capacity is balanced by outside inductances the more important become the effects of the self-induction except where the load is absorbed by synchronous motors, rotary transformers, or other apparatus which is capable of operating with a leading power factor, in which case the line capacity may be balanced by some form of load having a constant inductance and the line inductance balanced by a leading load variable with the reactance drop along the line. Indeed were it always possible to install long distance lines with a constant inductive load capable of neutralizing altogether the capacity effect; a variable synchronous motor or other leading load adjusted to neutralize at all times the self-inductive line; the problem of regulation in a long distance power transmission line would be reduced to the simplicity of the regulation in short direct current transmissions. With variable loads the capacity and self-inductive effects cannot truly be said to neutralize each other for the reason that the capacity effect is constant, and the self-inductive effect variable with the load, and where a long line is loaded altogether with lagging loads the conditions for regulation are the worst possible. This will be explained later, as we now further discuss the effect of capacity. One of the most noticeable effects of capacity is its action in reference to the wave form of the generators. Should a peaked wave form be delivered by the generators to a line containing a heavy capacity, the line would have the effect of somewhat neutralizing the generator defects, and will furnish to the translating devices at the delivery end of the line a smoother curve than was originally delivered by the generator, but where the generator curve is a sine curve, or as is more common with modern types of generators, a curve with a slightly flattened top, the capacity tends to increase this flattening. The extent of this action is illustrated in Figs. 1 and 2, which are reproduced from oscillagraph curves taken by Prof. E. E. Farmer, of the Stanford University, from the lines of the Independent Electric Light Co., of San Francisco. This company is not operating a long distance transmission system, but its circuits being all underground are of a high capacity and in consequence the necessary points are illustrated by these curves. In Fig. 1 the smooth curve is the electromotive force curve at the generating end of

the line. The rough curve being the corresponding current curve, the lines being unloaded except by reason of the capacity current. Fig. 2 is the same current curve as it is found at the point distant from the power house along the cables.

The peaked character of the current curves in this case seems to be due to the armature slots in the generator, since they correspond in number and position to these slots. That this is not due to any errors in the oscillagraph itself is shown in Fig. 3, which gives the electromotive force curve taken with both the

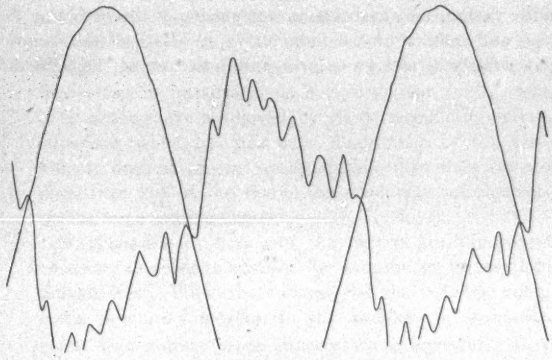

FIG .1.

FIG. 2.

current and electromotive force windings of the oscillagraph in series, and shows that the two windings give corresponding results when operated by the same wave form. Fig. 2 shows at once by examination that the effect of the capacity of the circuit has been to reduce the accentuation of the teeth of the current curve so illustrating the points made. The disadvantages that may arise from this condition were illustrated in the writer's practice in a line 45 miles in length, operated at 60 cycles and

25,000 volts. A synchronous motor was employed having a naturally bad wave form. The maximum point of the wave rising far above the point represented by the equivalent sine wave. In this case at no load the motor took full load current and at full load a current much in excess of the normal. The difficulty was remedied by paralleling the lines with a reactance coil. These experiments have been described in detail by the writer in a paper presented May 17, 1900, before this society. These results have been borne out more recently by observations made on a 140-mile line supplying synchronous motors of a better design, one synchronous motor being of the revolving field type, and another of the inductor type. Both of these motors give a fairly correct wave form, and in neither of them the diffi-

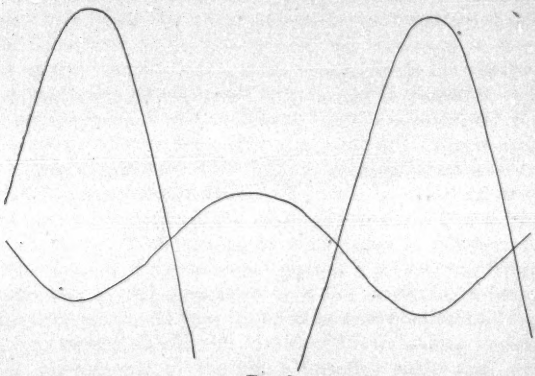

FIG. 3.

culty of the earlier experiments has been repeated, fortunately proving that the difficulty from modifications of the wave form in lines due to the capacity, can be overcome by the choice of correct motors. By far the most important effect of the capacity relates to the regulation of the transformers and generators attached to the line: A leading current taken from such apparatus having the effect of increasing the voltage, while a lagging current decreases it proportionately. This has nothing to do with the drop in voltage from the line itself, whether on account of resistance or self-induction, or to the rise along the line due to the capacity, but refers only to the action of the generating apparatus, and it

can readily be seen that where a line is operated sometimes with no load and sometimes at full load, the change of the power factor from leading to lagging will change the voltage beyond the calculated drop along the lines, and generally beyond the amounts allowed for in any regulating apparatus. Considering this point we see at once that the difficulty that was above spoken of is due to the variability of the self-inductive effect in the line itself, and points to the conclusions that were above drawn of the perfect line being one in which the capacity of self-inductive effect of the line is neutralized by a leading load variable with the variations of the load of the line. With lines of high capacity there is a rise in potential along the circuit, but though this effect has produced much discussion, its practical effect in importance is not very great, for the reason that it is entirely overshadowed by its corresponding effect on the apparatus which has just been described. In the case of the longest lines at present operated, this effect does not amount to more than 20% of the rise in the step-up transformers produced by the same leading current.

As it has already been said, the highest possible potentials are necessary in order to restrict the investment in very long transmission lines. When the voltages rise above 30,000 volts, phenomena becomes important in the problem of insulation which below that voltage were unnecessary to consider. In the first place voltages from 25,000 to 30,000 volts can be readily handled with insulators of either glass or porcelain having a diameter not exceeding seven inches. Pieces of glass or porcelain of these dimensions are mechanically strong and are readily manufactured. Where the voltage rises to 50,000 to 60,000 volts, and the sparking distance between the lines increases to between five and six inches, the insulators must have a diameter of at least 12 or 13 inches and be held not less than 7 or 8 inches above the crossarm. Such pieces of these fragile insulating materials are difficult to manufacture, and though the problem has been successfully solved, the greatest care in design and manufacture is absolutely essential, though it is believed that the factor of safety of high potential insulators as at present designed is by no means as great as that commonly employed with the lower voltages. An even more striking difficulty in handling high voltages lies in the effect of the electrical surface tension which, with high voltages and small wires results in a brush dis-

charge and high energy loss independent of leakage over the surface of the insulators, being simply an escape to surrounding bodies from the whole surface of the wire. This we believe was first noticed by Scott and Mershon in their Telluride experiments, which experiments have been confirmed by the engineers associated with the writer in carrying out high voltage work. Stated simply, it is found that the electrical tension along the line operating at 50,000 or 60,000 volts renders the use of wires smaller than about $\frac{3}{8}''$ diameter a dangerous expedient, resulting in important losses, which again points to the fact that high potential long distance transmissions cannot be successfully carried out unless the power to be transmitted is in itself large, warranting the use of conductors of great size.

The important phenomena which rise to view in carrying out the long distance problem have now been presented, and it remains only to call attention to the fact that in this long distance transmission work extraordinary precautions must be taken to maintain the permanence of supply. Long distance transmission means, as we have said, large powers; and large powers delivered at distant points presuppose important engineering undertakings at the delivery end of the line which call for absolute continuity of supply. The poles must be selected and erected with more than ordinary care. The lines must be constantly patrolled. Trees cannot be simply trimmed, but a right of way almost as wide as a railroad right of way secured, and all obstructions of the nature of trees which may fall across the line in high winds removed. The use of the ordinary insulating materials in power houses and supply stations, such as paraffined wood and paraffined marble, must be entirely abandoned or relied upon only as minor auxiliaries, and, finally, wherever it is possible, either steam or storage battery auxiliaries at the delivery end of the line furnished. It seems almost unnecessary to call attention to the design of the apparatus in the generating station, but it is perhaps well to mention the fact that the generator and tranformer designers may aid the installing engineer very materially by paying particular attention to regulation at the lower power factors even at the cost of some efficiency, should that be necessary. The designer should always remember that regulation in long distance transmission is regulation at other than unity power factor.

The engineering problem, therefore, by its very bigness is one requiring the most careful solution at its every step, and the fact that is being now successfully carried out merits the highest praise both toward the engineers and designing, and the investors whose faith in their engineers permits the employment of the necessary capital to do the work thoroughly.

The points made in this paper have all at one time or another been particularly discussed before the INSTITUTE, and the writer only ventures to bring them together in this sketch in the hope that new points of view may be attained by their discussion in relation to the whole problem.

*A paper to be presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 23rd, 1901.*

[ADVANCE COPY, SUBJECT TO REVISION.]

# DEVELOPMENT OF THE NERNST LAMP IN AMERICA.[1]

BY ALEXANDER JAY WURTS.

It was in 1897 that Mr. Henry Noel Potter, while in the employ of Mr. Westinghouse, at Goettingen, became acquainted with the Nernst lamp. Early in 1898, Dr. Nernst, Mr. Potter and an assistant came to East Pittsburg at Mr. Westinghouse's request and exhibited the new discovery. Mr. Westinghouse quickly recognized its great possibilities and directed the writer to prepare for its commercial introduction. A happy choice brought Mr. Marshall W. Hanks to my assistance. Mr. Potter returned to Goettingen to study some of the details of the work. In June, 1899, Mr. Edward Bennett joined us, as did also Mr. Frederick M. Goddard a month or two later, who had been assisting Mr. Potter in Germany, but unfortunately in December of that year, Mr. Goddard contracted a violent cold from which he never recovered. In February, 1900, Mr. Murray Charles Beebe joined us and in August of the same year, Dr. Max von Recklinghausen.

I have thus briefly introduced the characters who have worked upon the Nernst lamp in America and without whose names its

1. EXPLANATORY NOTES.—The Hefner unit of candle power has been adopted in this paper so that ready comparisons may be made with results obtained on the Nernst lamp in European countries.

*Names of Parts in the Nernst Lamp:*—The "glower" is the filament or light-giving body. The "ballast" is a steadying resistance connected in series with each glower. The "holder" is the removable piece containing glowers and heaters. The "heater-porcelain" is the porcelain disk in the holder immediately back of the heater. The "heater-case" is a small glass globe used in the six-glower and thirty-glower lamps.

history would be incomplete; my only regret being that these gentlemen are not all present on this occasion to share in the pleasure of announcing to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS the results of our work upon the Nernst lamp.

## THE GLOWER.

It is not my purpose to describe the details of our experiments, but rather to give the results of our work. Let us begin with the glower, so named to distinguish it from the filament of the incandescent lamp.

Our standard 220-volt glower is about 25 millimetres long and .63 of a millimetre in diameter. It is made by expressing from a die a dough made of the rare earths mixed with a suitable binding material, cutting the porcelain-like string thus made into convenient lengths, drying, roasting, and finally attaching lead wires. This sounds very simple, but the making of glowers is an art not easily acquired; it is the result of long and painstaking investigation, particularly with reference to the terminal connection between the glower and lead wire. This connection, as Dr. Nernst made it, consisted of a few turns of platinum wire wound around each end of the glower, the convolutions being finally pasted with cement. This forms a successful and effective terminal, but the shrinkage of the glower ends, away from the convolutions of platinum wire sometimes causes the contact to deteriorate, resulting in the weakening and early destruction of the glower near the terminal. In the Hanks terminal, these conditions are reversed. A platinum bead is embedded in the end of the glower in such a manner that any tendency to shrink on the part of the glower material can result only in tightening the contact and thereby maintaining intimate union between the platinum bead and the glower. It is, then, a simple matter to fuse lead wires to the embedded platinum beads.

The glower, as you all know, is a non-conductor when cold, becoming, however, a conductor when heated. It is also an electrolyte; but it may be fairly stated that this phenomenon is not clearly, if at all, understood. Oxygen, however, seems to be necessary, or at least desirable, for its successful operation. As might be expected, no electrolytic action is apparent when operating with alternate current. With direct current, the electrolytic action is quite marked, resulting in a black deposit on the negative end of the glower, which spreads gradually from

the negative toward the positive terminal. As this deposit increases, the voltage of the glower changes somewhat, and the candle power and efficiency fall off, owing to the poor light-emitting properties of the blackened portion. The life of the glower on alternating current is about 800 hours; with the same glower on direct current, it is considerably less than this. There are, however, radical improvements being made in direct current glowers.

A glower burns at a higher efficiency in its own heat, that is, in a globe, than it does in the open air. We shall refer again to

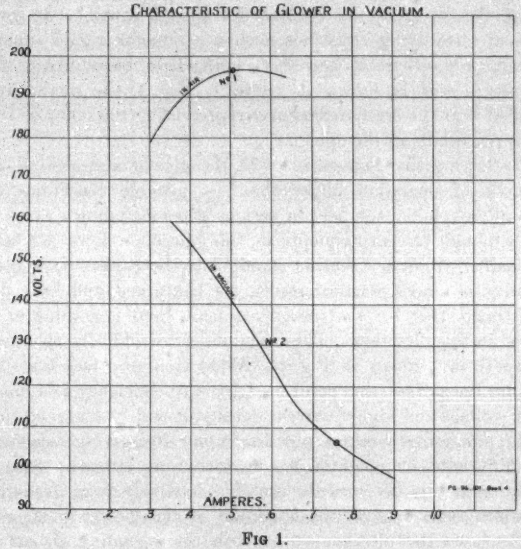


FIG 1.

this feature in connection with the multiple glower lamp. The glower is about as strong as a piece of porcelain of the same size, and it is difficult to break a short section. The terminals of a glower give off platinum black, which deposits on the globe; and although this cannot be wiped off with a cloth, it is easily removed in a variety of ways, so that the globe may be considered a permanent fixture in the lamp, and, for that reason, may assume fancy designs. When properly made, the voltage of a glower

changes but slightly during its life, the tendency being to rise from two to four per cent. in 800 hours. For a short time before rupture, the voltage rises rapidly until the glower is broken.

The characteristic of a glower with reference to voltage and current is remarkable, and has given rise to the necessity of a steadying resistance. As the current in the glower is increased, the voltage across its terminals rises, at first rapidly, and then more and more slowly to a maximum, beyond which it again drops off with increasing rapidity as the current and resulting temperature through the glower continue to increase. Beyond the point of maximum voltage, the decrease in resistance of the glower is so rapid as to make the current difficult of control. In fact, without a steadying resistance, such a conductor would rapidly develop a short-circuit and flash out. The characteristic of a Nernst glower is shown in curve 1, Fig. 1, the small circle situated near the crest of the curve representing the point of 1.76 watts per candle in the open air.

In studying the characteristics of the glower and seeking for methods of operation under the best possible conditions, we naturally exploited the field in various gases including a vacuum, and although the experiments in this direction have not been exhaustive from a scientific standpoint, the results have been negative as far as practical results are concerned, and have demonstrated that for the present, at least, there is nothing to be gained in this direction. The vacuum curve and corresponding air curve are shown in Fig. 1. Aside from the fact that the vacuum has shifted the point of 1.76 watt efficiency to a much lower voltage and higher current density, it will be observed that all the points of the curve now lie on one side, giving a decreasing difference of potential for an increasing current. Such a condition as this involves the use of a relatively large steadying resistance, and renders the operation of the glower inefficient. Fig. 2 shows the nitrogen curve with corresponding air curve, and it will be observed, as in the case of the vacuum, that this gas has also rendered necessary a large steadying resistance and has thereby lowered the available efficiency of the glower. In Fig. 3, we have both the oxygen and hydrogen curves to compare with the air curve. It is interesting to note how closely the oxygen and air curves compare with each other, while the hydrogen curve shows characteristics similar to that of the vacuum curve requiring a large steadying resistance.

There is an interesting phenomenon connected with glowers operating in a space free from oxygen, and which seems to be especially pronounced when operating in a vacuum. Where oxygen is excluded, the glower seems to be sluggish and to respond but slowly to changes in line voltage. The curves in Fig. 4 show this sluggish action in a vacuum. The line voltage is indicated by a dotted line in the upper part of the diagram, beginning with 270 volts. The upper solid curve shows the change of current value during a lapse of time indicated in minutes; while the lower curve shows the change in voltage on the glower during the same interval. Previous to this test, the glower had been run at .25 of an ampere for half an hour, after which the

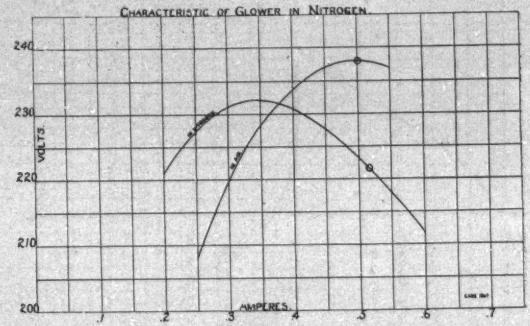


FIG. 2.

line voltage was raised 20 volts and the current values and differences of potential on the glower were taken at intervals for ten minutes, resulting in the curves shown. Shortly after the completion of this test, the line voltage was lowered 20 volts, when the glower again adjusted itself slowly to the new conditions, and returned to its original current and difference of potential. In air, the glower would have responded almost immediately to similar changes in line voltage. It is likely that the slight changes in both cases after the first minute are largely, if not entirely, due to the temperature correction of the resistance that was connected in series with the glower.

## Steadying Resistance or Ballast.

The advantage to be gained by the use of a steadying resistance which would enable the glower to be operated efficiently at a point on or beyond the crest in the characteristic curve, was well recog-

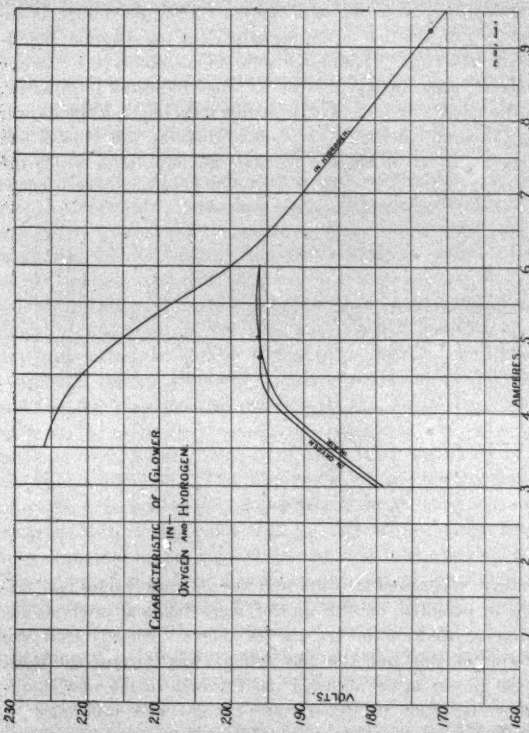


Fig 3.

nized. To accomplish this under all conditions of commercial use, and with as little loss as possible under normal conditions, the steadying resistance should have as large a positive temperature correction as possible and this temperature correction should always be immediately available. For example, if the glower were operated on or beyond the crest of the characteristic, the

current could obviously be controlled by a sufficiently large steadying resistance having no temperature correction, but such resistance would very materially decrease the net efficiency of the glower. On the other hand, if the resistance is assumed to have

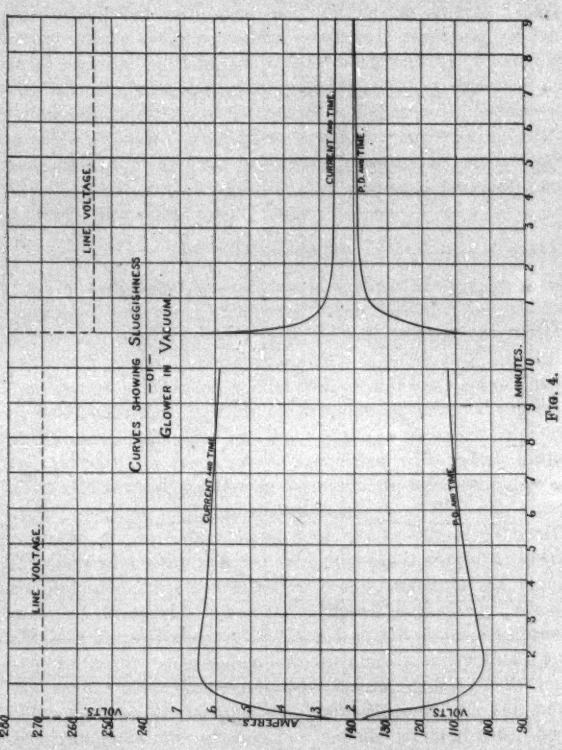


FIG. 4.

a high temperature coefficient, the necessary steadying resistance under normal conditions may be very much less than when no temperature correction is present, and then should there be an increase in electro-motive force above normal, the corrective power of the steadying resistance would be brought into play to check any abnormal flow of current through the glower; in other

words, to take up the additional voltage. As already stated, however, the temperature correction should be *immediately* available, for if it were not, the glower would "shoot over" when lighting above the normal pressure, that is, take more current at the start

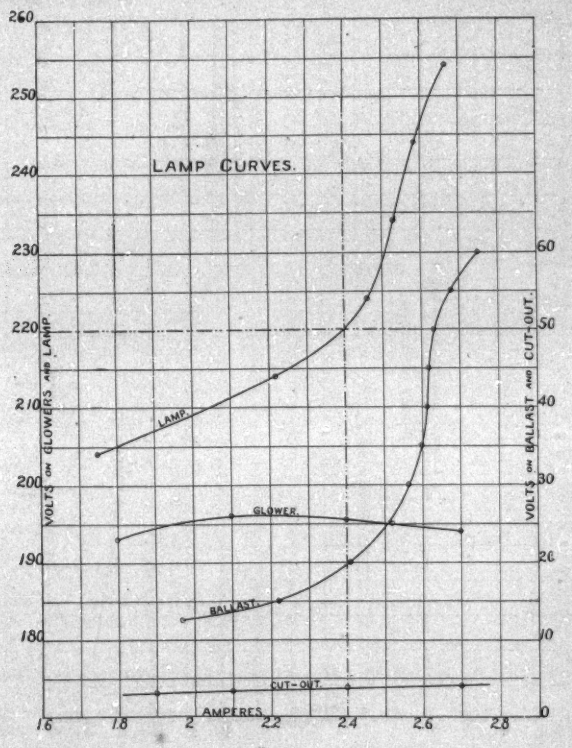


FIG. 5.

than it would a little later after the temperature correction of the steadying resistance had asserted itself. The same would also be the case with any sudden increase in the electromotive force applied to the glower, unless the corrective power of the steadying resistance were immediately available to check the current flow.

Mr. Potter has designed a steadying resistance or "ballast," as he has named it, which is certainly unique in construction and which meets in a very effective manner, the peculiar requirements of the glower. Iron wire is used on account of its high temperature correction, and by properly mounting this in a small glass tube filled with some inert gas, he has secured a ballast having at once a high corrective power with minimum resistance under normal conditions and oxygen being entirely excluded, the wire can readily be worked throughout the entire high corrective region without danger of destruction. This remarkable characteristic of the ballast is well shown in Fig. 5, from which it will be noticed that for a 10% rise in current, the resistance of the ballast increases 150%, so that a glower thus protected becomes at once operative throughout a wide range.

## The Heater.

As already stated, the glower is a non-conductor when cold, becoming, however, a conductor when heated. For practical service in a lamp, therefore, it is necessary that some means be provided for heating the glower and bringing it to a conducting temperature. This topic could well form the subject of a paper by itself, but time will permit me to review but briefly the developments made in this direction. Some of the lamps which Dr. Nernst brought with him from Europe were fitted with electric heaters, while others were intended to be heated by an alcohol lamp or even by a match. The further refinements of the lamp imposed new and severe requirements upon the heater. It is therefore especially gratifying that we can announce the construction of a simple, satisfactory and effective heater, suited to the requirements of the latest forms of the lamp. The glower is lighted at a temperature of about 950° C., and it will be readily apparent that to acquire such a temperature quickly and without rapid destruction of the heater and adjacent parts, renders the section of the materials a very serious problem. Platinum for the heater seems an undesirable expense in a commercial lamp, and although many attempts have been made to devise a cheap mineral heater, platinum still holds its own as the least expensive, the most durable, and altogether the most desirable material for this purpose. The actual expense, however, is not so serious, because when the platinum heater is burned out, the value of the scrap is nearly 90% of the original cost, and as the labor is almost negligible, the running cost of the heater is small.

As now constructed, the heater consists of a thin porcelain tube overwound with a fine platinum wire pasted with cement, the latter serving as a protection to the platinum wire from the intense heat of the glowers. These tubes are wound for 110 volts and are connected in pairs of two in series according to the service, the one, two, and three-glower lamps taking one pair, and the six-glower two pairs. These heater tubes are mounted on a porcelain support in such a manner as to afford easy access for repairs without removing the glowers. The life of the heater when running continuously is about 200 hours, or 133 hours

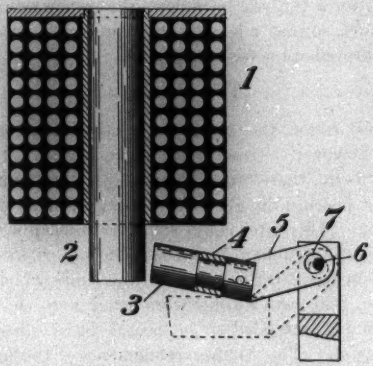


FIG. 6.

when the current is turned on and off 4,000 times at regular intervals. Inasmuch as the heater is not called into service for more than about 30 seconds to light the glowers, this would indicate a practically infinite life. In actual service, however, the heater remains in close proximity to the glowers and the high temperature to which it is thereby subjected causes a material decrease in its life. Nevertheless, the life of the heater is surprisingly long, probably several thousand lamp hours. The average life, however, cannot be definitely determined until a large number of lamps heve been operated over a very considerable period in general commercial lighting.

## Cut-outs.

An automatic lamp requires a cut-out to disconnect the heater from the circuit as soon as the glower shall have lighted. This is another one of those details that Dr. Nernst developed and exhibited in some of his early lamps, but which we have sought to still further perfect and to adapt to the special types of lamp which we have constructed. The cut-out includes a coil, a moving member and a contact, all of which must function at a temperature of about 110° C. without possibility of failure. The coil must therefore be heat proof, the contact must not weld, and the moving member should not hum on alternating current. These requirements are severe, but they have all been met in a most effective and satisfactory manner by embedding the coil in cement, by making the contact of silver, and by suspending the moving member from a single point of support.

The latter feature of the cut-out is illustrated in Fig. 6; 1 is the coil; 2 the core; 3 the armature or moving member, which is round in section; 4 is a silver band which makes contact by gravity with two silver wires not shown, forming a V; 5 is a strip of sheet steel .007 of an inch thick, which is inserted into the armature and securely held by a pin; 6 is small steel rod or support for the armature; and 7 is a hole in the steel strip 5, somewhat larger in diameter than the pin 6, so that when the armature is attracted by the magnet, there is practically only a single point of contact between the strip 5 and the supporting pin 6. This construction has resulted in a cut-out which entirely avoids the humming sound so persistent in the ordinary types of alternating current apparatus.

## Lamps.

The lamps thus far developed are indicated in the following table:

| Candle Power. | Voltage. | No. of Glowers. | Style. |
|---|---|---|---|
| 50 | 110 | 1 | Indoor |
| 50 | 110 | 1 | Outdoor |
| 50 | 220 | 1 | Indoor |
| 50 | 220 | 1 | Outdoor |
| 100 | 220 | 2 | Indoor |
| 170 | 220 | 3 | Indoor |
| 400 | 220 | 6 | Indoor |
| 400 | 220 | 6 | Outdoor |
| 2000 | 220 | 30 | Indoor |

The main features are the same in all. The indoor lamps are provided with ornamental spun brass housings; the outdoor lamps with neat japanned cast-iron housings. Single glower lamps have single pole cut-outs, whereas all the multiple glower lamps are provided with double pole cut-outs, the reason for this difference being that the extremely high temperature in the immediate neighborhood of a number of glowers tends to establish leakage currents between the glowers and heaters, unless the latter be entirely disconnected from the circuit.

We will examine in detail the six-glower lamp as typical of all the others. This lamp is suspended from an eye-bolt which being removed, allows of immediate access to the inner parts. On removing the housing, we find that the ballasts are placed in a semi-circle around the cut-out, the arrangements of the parts being such as to make all easy of access. The connections are made with small aluminium plugs on the ends of the interconnecting wires which avoid the many familiar inconveniences associated with set screws. All the parts are mounted on porcelain; in fact, there is no combustible material whatever in the lamp. The heaters and glowers are attached to a removable piece or "holder," the design being such that the heaters backed by a porcelain disk are immediately above the glowers, resulting in the following advantages: Stagnation of heat from the heater, thereby lighting the glowers in minimum time; no shadows, nearly all the light being thrown downward where it is ordinarily most desired; stagnation of heat from the glowers whereby the latter are run in their own heat and therefore at a higher efficiency than they would otherwise. The glowers and heaters are attached to the binding posts of the holder by means of small aluminium plugs, so that the perishable members are always easily and conveniently interchangeable. The holder is provided with nine contact prongs, which, when the holder is pushed up into the lamp, automatically make the desired connections. These are shown in Fig. 7; 1 and 2 represent the line terminals; 3 the actuating coil; 4 and 4 the double pole cut-out; 5 the heater; 6 the glowers; and 7 the ballasts, there being, of course, one ballast for each glower. A small glass globe, called the "heater-case," is held by spring clamps around the glowers, the function of which is to retain the heat and thereby decrease the time of lighting as well as increase the efficiency of the glowers. In service, the "heater porcelain," which is the porcelain disk

immediately above the heater, becomes coated with a thin layer of platinum black, unless measures are taken to prevent it, and this not only decreases the illuminating power of the lamp, but if not removed, will in course of time become conducting and cause leakage of current. No simple means have been discovered for

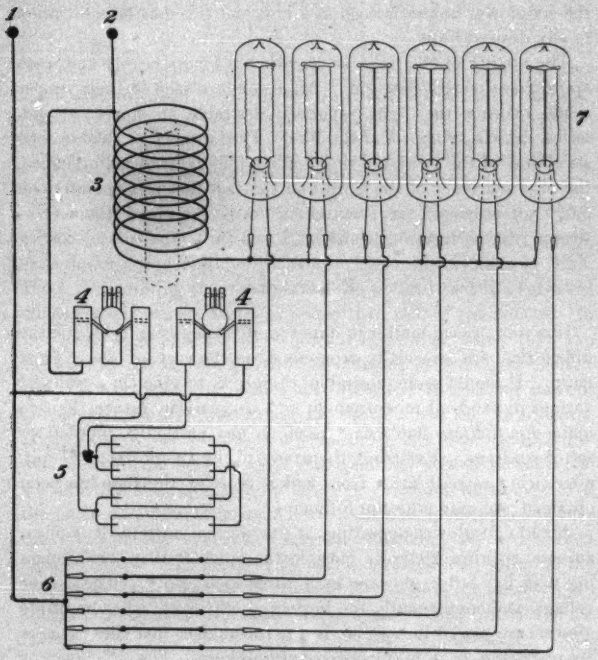


FIG 7.

removing the platinum black from the porcelain surface. This difficulty, nevertheless, has been avoided by coating the surface of the porcelain with a thin layer of white paste, which may be easily removed with a stiff brush or scraper. The platinum black now deposits on this coating, both of which may be removed together, leaving the fresh, white surface of the original porcelain to be recoated for further service; but even should the

platinum black be allowed to accumulate, all danger of leakage currents is avoided by surrounding the holes through which the lead wires pass, by small annular rings or grooves, it having been discovered that the platinum black will not deposit in these small spaces; the continuity of the platinum black surface between the lead wires is thereby interrupted. For higher candle powers, the six-glower holder is used as a unit and this may be multiplied to any desired limit.

The quality of the light is remarkable for its beauty and close approximation to daylight. All colors are seen in their proper shade, making the light especially desirable in stores, art galleries, drawing-rooms and the like. The absence of shadow, the steadiness of the light, the simplicity and low cost of maintenance, the high efficiency of the lamp, and the fact that it is operative on 3,000 alternations, are features that will commend themselves strongly to the lighting world.

## Efficiency.

It is not an easy matter to state the efficiency of a light, and the difficulties are especially pronounced in the case of the Nernst lamp. It would seem desirable, therefore, to give the results of various methods of measurement and comparison rather than to make any definite statement based on any particular method or set of readings. Referring, therefore, to the six-glower, 220-volt, alternating current lamp, from which most of the data has been obtained, we may note the following:

A 220-volt glower operating at its normal current of .4 of an ampere, requires 20 volts more in the open air than when burning with five other glowers in a three-inch globe. The lower voltage and consequently the improved efficiency, when multiple glowers are placed in a globe, is due to the fact that the glowers are operating in a highly heated atmosphere. The efficiency of the six-glower lamp with clear heater case, but without the dome shade, is 1.2 watts measured in the direction of greatest intensity.

A more satisfactory statement will be found in the accompanying table giving the spherical and lower hemispherical efficiencies of the six-glower Nernst lamp, together with the corresponding figures for alternating current and direct current enclosed arc lamps:

| | | | | | Mean Intensity in H. U. | | | | | | Watts per Mean H. U. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Spherical. | | | Lower Hemisphere. | | | Spherical. | | | Lower Hemisphere. | | |
| | Voltage. | Current. | Watts. | Power Factor. | Opal Outer. | Clear Outer. | Shade. | Opal Outer. | Clear Outer. | Shade. | Opal Outer. | Clear Outer. | Shade. | Opal Outer. | Clear Outer. | Shade. |
| 6-Glower. | 220 | 2.35 | 517 | 1.0 | 149* | — | 147 | 240* | — | 279 | 3.47 | — | 3.5 | 2.15* | —— | 1.85 |
| A. C. Arc. | 110 | 6.29 | 417 | .6 | 130 | 159 | 152 | — | 190 | 254 | 3.21 | 2.62 | 2.49 | — | 2.23 | 1.48 |
| D. C. Arc. | 110 | 4.9 | 539 | 1.0 | 177 | 207 | — | — | 272 | — | 3.03 | 2.60 | — | — | 1.98 | —— |

An opal inner globe or heater-case was used in all cases except the four readings marked *.
*A clear heater-case and sandblasted spherical globe were used.

The arc lamp figures were taken from the Report of the Committee for Investigating the Photometric Values of Arc Lamps, read before the National Electric Light Association in May, 1900. Examining this table, it will be noticed that the spherical efficiency of both arc lamps is better than that of the Nernst. In the lower hemisphere, the Nernst is somewhat better than the alternating current arc and not as efficient as the direct current arc. When reflecting shades are used, the alternating current arc again has a slight advantage for the whole of the lower hemisphere; but if we disregard the mean of the lower hemisphere and consider the floor or desk illuminating power of the lamp, we find that the Nernst lamp has a very decided advantage over the enclosed alternating current arc; for example, if we consider the mean of the lowest 30° zone, the efficiency of the enclosed alternating current arc is 1.56 watts against one watt for the Nernst and the mean of the lowest 60° zone is for the enclosed alternating current arc, 1.45 watts against 1.23 watts for the Nernst.

Comparisons between the illuminating powers of the Nernst and incandescent lamps indicate a watt consumption in the Nernst lamp a little less than half of that in the incandescent for equal illumination. The superior quality of the Nernst lamp is also very marked both for reading purposes and for the correct determination of color.

A similar comparison between the illuminating power of the Nernst and enclosed alternating current arc lamps shows for an equal consumption of watts in the two lamps, a much superior

floor illumination for the Nernst lamp. Although the measurement shows a slightly better general illumination for the arc lamp, yet the quality and steadiness of the Nernst light, together with the entire absence of shadow, give an impression of decided superiority in favor of the Nernst.

The two sets of curves, Figs. 8 and 9, show interesting com-

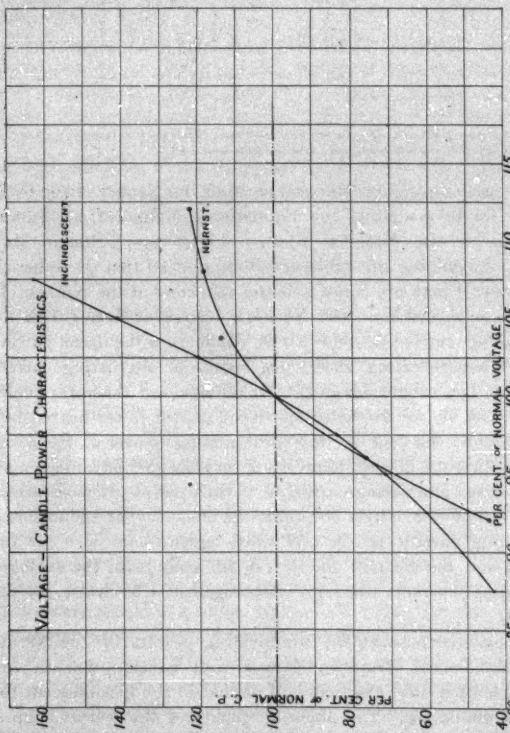


FIG. 8.

parisons between the Nernst and incandescent lamps under conditions of varying voltage. Fig. 8 shows the relative change in candle power and Fig. 9 the relative change in efficiency, all the variations in each case being given in per cent. of normal conditions. These curves are self-explanatory except as to the remark-

able steadiness of candle power in the Nernst lamp when forced above normal voltage. The feature is due to the great corrective power of the iron ballast.

At present our data regarding the effect of running Nernst lamps at different efficiencies is rather limited. Figures of this character require many readings under all kinds of conditions and it may be some time before these can be satisfactorily and definitely recorded, but roughly, it may be stated that the efficiency of the glowers falls but slightly during their natural life, provided the lamps are kept properly cleaned.

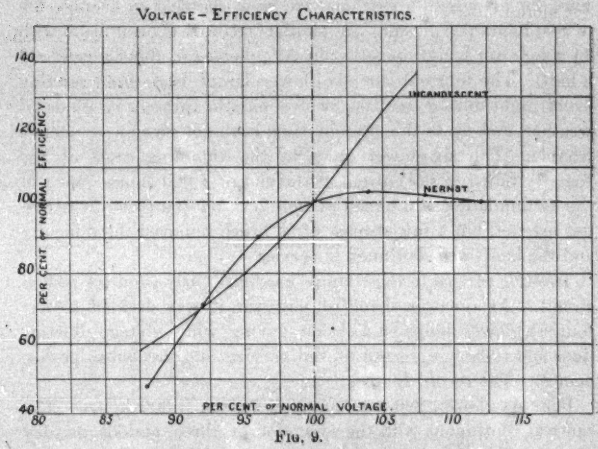


FIG. 9.

## PERFORMANCE OF THE LAMP.

At the present writing, July 15th, there are in operation at East Pittsburg, 73 six-glower lamps, one three-glower and three single glower; in our laboratory and shop at Allegheny, 40 six-glower, 10 three-glower, and 21 single glower lamps; in the courtyard we have four outdoor six-glower lamps and in the tumbling room of the foundry, one outdoor six-glower lamp, all running on alternating current at 220 volts. In addition to these, there are 14 single glower direct current 110-volt lamps in Mr. Westinghouse's residence, making a total of something like 50,000 candle-

power in and about Pittsburg. At the Pan-American Exposition, we have lighted the interior of the dome of the Electricity Building by festooning 92 six-glower lamps from a pendant chandelier consisting of a central lamp of 30 glowers and 2,000 candle power encircled with six lamps of the six-glower type; on the floor, variously distributed, there are 12 six-glower, 24 three-glower and eight one-glower lamps. These figures are intended to give some idea of the scale on which the Nernst lamp has been developed and the resources which have been placed at our disposal.

Seventeen six-glower lamps have been running at East Pittsburg for more than a year, and are now showing an average life of 800 hours per glower. A similar record has been made with 14 six-glower lamps operating in Allegheny for about a year and a half. The four outdoor six-glower lamps have been running every night during the last twelve months through all kinds of weather, and up to the present time have not given a moment's trouble. The six-glower lamp in the tumbling room of the foundry failed in the cut-out at the end of 1,000 hours owing to the accumulation of a bunch of iron dust on the pole of the cut-out magnet, but a few strokes of a brush removed the difficulty and the lamp was continued in service.

The line service to these lamps has been fairly good for a shop circuit. As a matter of record, however, it was decided to test four six-glower lamps on a circuit having wide voltage fluctuations and to keep a record of the service and the lamp performance. The record follows:

Four six-glower, 220-volt lamps were run 1,000 hours. The run was continuous with the exception of three periods per day of one-half hour each when the lamps were turned off. A record of the voltage was kept with a Bristol recording voltmeter. An inspection of the voltmeter cards show that these may be classified under three types. Of the first, there were 15 cards, indicating that the voltage did not rise higher than 229 volts and only remained there for a short period. Of the second type, there were 26 cards, in which the voltage reached a maximum of 232 volts, maintaining this for about four hours. Of the third type, there were four cards showing a rise of voltage to 237 and remaining at 235 for five hours. These cards show that the lamps have been tested on a circuit, pressure of which varies from 4% below to 7½%

above normal. There were no ballasts or heaters burned out during this run, nor did the lamps receive any attention or give any trouble.

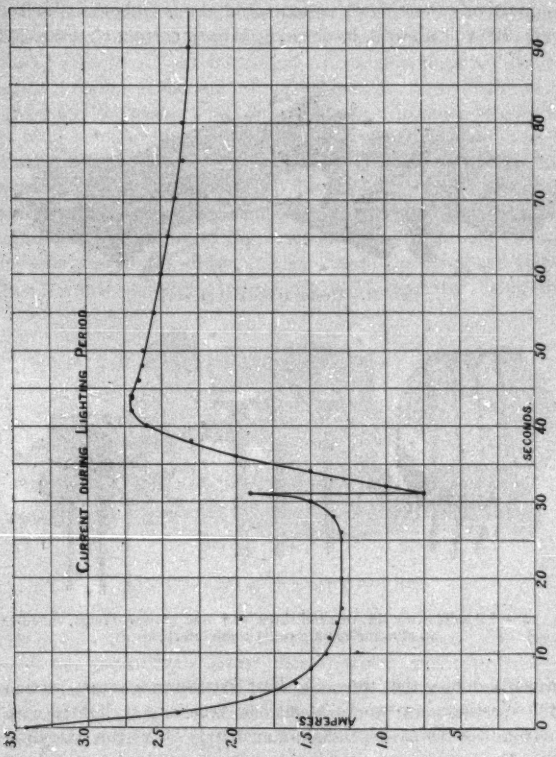


FIG. 10.

Of the 24 glowers in these lamps,

15 ran 1,000 hours;
6 ran 792 hours;
1 ran 580 hours;
2 ran 380 hours;

making an average of 890 hours.

The three, two and one-glower 220-volt, alternating current lamps have given equally satisfactory service, but the glowers in the 110-volt alternating current lamp are not quite so uniform in their performance and the same glowers on direct current are comparatively short lived, averaging in the neighborhood of 150 hours; 220-volt glowers, however, on a direct current circuit would

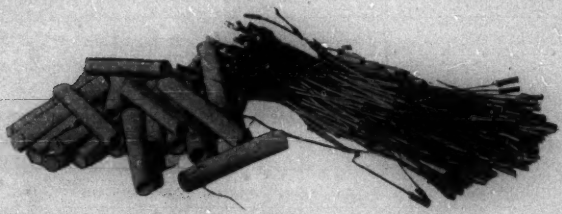

FIG. 11.—Heater tubes and glowers.

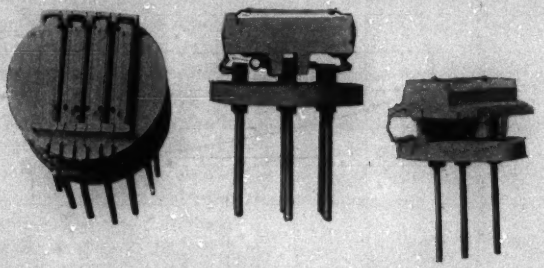

FIG. 12.—Holders for the six, two and three, and one glower lamps, showing an aluminium plug ready to be inserted.

last nearly double that time. At East Pittsburg, where a section of the Westinghouse works, about 350 feet long is lighted with 50 six-glower lamps suspended immediately above the traveling cranes, the features which strike me more forcibly than anything else are the beauty of the illumination and the total absence of shadow and flicker so intimately associated with the electric arc illumination in places of this character.

In connection with this topic, it will be interesting to note just what is going on in the lamp during the time of lighting, also during service under varying conditions of line voltage. Refer-

ring to Fig. 10, we have a curve showing the current taken by a six-glower 220-volt lamp during the lighting period. It will be noticed that as the current is turned on, there is a sudden rush of nearly 3.5 amperes through the heater, which, owing to the temperature correction of the platinum wire, is quickly reduced to about 1.3 amperes. At the end of 26 seconds, the first glower begins to light; at the end of 30 seconds, the second glower is lighted and the heater is cut out, the current dropping at once to .75 of an ampere; the remaining glowers then light rapidly until at the end of 40 seconds all the glowers are lighted. From this point on, there is a slight drop in the current until the lamp reaches its normal running temperature.

Referring once more to Fig. 5, we find the current and voltage characteristics of the different elements in the lamp, and above these the characteristics of the lamp itself, the latter being the

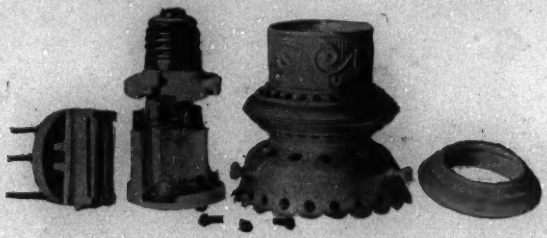

FIG. 13.—Parts of the single glower lamp.

sum of the cut-out coil, the ballast and the glower. The lamp curve was taken from actual measurements and approximates very closely to the sum of the elements, the slight difference probably being due to some differences of temperature. The voltage scale for the cut-out and ballast curves will be found on the right hand side of the diagram; that of the glower and lamp on the left hand side. Your attention is now directed to the excellent characteristic of this lamp, and when we consider the severe conditions imposed by the glower characteristic, I think we are to be congratulated on the results which have been attained. With a normal in the lamp of 2.4 amperes and 220 volts, it will be noticed that an increase of 14% in voltage causes but a 10% increase in current, resulting in a comparatively steady light

and safe running conditions for the lamp in commercial service. A rise of 25% in the line voltage would burn out the ballasts in a very short time, but a rise of 10% for short periods does not seriously affect the life of either glower or ballast; a rise of 5% may be considered allowable for indefinite periods.

## Repair and Maintenance.

When the lamps are first started, they require no attention. After 1,000 hours, however, the renewals become fairly regular and our experience shows an average life of 800 hours for the glowers, 2,000 to 3,000 hours for the heaters and an indefinitely long life for the ballasts. It will, however, be some time before

Fig. 14.—Two and three glower lamp, indoor type.

Fig. 15.—Six glower lamp, indoor type.

the average life of the heaters and ballasts can be definitely determined. The attention which these lamps receive, consists in having the inspector examine the lamps once a week through a colored glass to determine whether or not all six glowers are burning. If two glowers are out, the lamp is turned off, the holder removed and two new glowers inserted; the holder is then returned to its place and the lamp continued in service. Aside from such renewals, these lamps have not given the least trouble.

On the occasion of starting up 50 six-glower lamps at East Pittsburg, one of the engineers who had had considerable ex-

perience with arc lamps, remarked that my troubles would now begin; but, frankly, I think he was mistaken. Aside from the renewal of the perishable parts, I see nothing in the lamp which could possibly cause trouble except under the most extraordinary circumstances. In fact, should a lamp receiving proper attention fail to light, I would look for the trouble elsewhere than in the lamp.

In commercial service it is intended that the central station shall make the renewals in the holders. The customer will be

FIG. 16.—How to grip the holder without disturbing the glowers.

FIG. 17.—Six-glower lamp, outdoor type.

provided with a case containing a suitable number of complete holders, ready for service, so that when a renewal is to be made, the customer will simply remove the old holder and insert a new one, such operation consuming but a moment's time; then, at convenient periods, the old holders will be exchanged for new. Where lamps are used in quantity, the renewals will probably be made by the local attendant. The replacing of a ballast requires the removal of the lamp from the circuit, but after that the renewal is easily and quickly made. A slight withdrawal of one

screw releases the ballast tube from its socket, whereupon the small aluminium terminal plugs may be withdrawn and the new ballast inserted. This operation does not require any tools other than a pair of small tweezers, and the renewal can be made without returning the lamp to the workbench.

After about 100 lamp hours, the heater case becomes somewhat discolored, and, for first-class maintenance, this should be cleaned at the end of that time. The following instructions for the care and inspection of the Nernst lamps are observed at East Pittsburg:

FIG. 18.—Thirty-glower lamp, indoor type.

FIG. 19.—Single glower lamp, indoor type.

*Inspection of the Lamps.*—The lamps should be inspected every 100 lamp hours. After being turned off, the lamp is turned on, and it is noted whether all the heater tubes become bright. If any of the heater tubes are burned out, the holder is replaced by a new one.

If the heaters are intact, the number of glowers burning is determined. If five or six are burning, the lamp needs no attention.

If less than five glowers are burning, the lamp is to be turned off, the holder taken out and the number of broken glowers determined by inspection. If the number of broken glowers is less than the number of glowers that were out, one or more ballasts

are out of order and the lamp is to be taken down at once and the defective ballast replaced. When two or more glowers are burned out, the holder is to be replaced by a reserve holder.

*Ballasts.*—These are supplied in boxes marked "Ballasts for six-glower lamps," "Ballasts for one-glower lamps," etc. Burned out ballasts are to be renewed as soon as discovered and may be replaced without taking the lamp to the workbench.

*Heater-Case.*—This receives a coating of platinum black on the inside and should be replaced every 100 lamp hours by a clean heater case. The coating may be removed from the old heater case with a bristle brush running at a hight rate of speed. The heater case may then be used over again.

*Glowers.*—These are supplied in glass tubes marked with the voltage of the lamp for which the glower is intended, thus, "Glowers for 220-volt, six-glower lamps." Glowers marked for six-glower, are not to be used in a three or one-glower lamp and vice versa.

*Heaters.*—These are wound for 110 volts and are so marked. They are connected two in series for 220 volts. In the six-glower lamp there are four tubes connected in multiple series.

*Heater Porcelain.*—(This is the porcelain disk immediately behind the heater.) The heater porcelain is given a white coating which becomes fairly hard, but can be easily scraped or brushed off when it becomes covered with platinum back. When a holder with a black heater porcelain is removed, the glowers should be taken out, the old coat brushed off, except directly under the heater tubes, and a new coat of "heater porcelain paste" applied. This paste is a white powder which is to be mixed with water and applied with a camel's hair brush. After replacing the heater porcelain and allowing it to dry in the air, run the heater for two minutes on 220 volts, placing the holder in a heater case. This hardens the coating, after which the glowers may be replaced.

*Cost.*—It is too early to say anything definite about the cost of these lamps. Fourteen or fifteen dollars would seem to be a fair price for a six-glower lamp, other lamps in about the proportion of the number of glowers. It is estimated that the cost of renewals will be considerably less than for enclosed arc lamps. Provision will be made for the return of the perishable parts containing platinum.

## Conclusion.

In closing, let me say that the Nernst lamp can in no sense be considered an experimental device. The development of details connected therewith has continued until all question of doubt as to its commercial success has been removed by the operation of a large number of lamps of various sizes and finished pattern for extended periods under commercial conditions, and it is confidently felt that the splendid exhibit of these lamps which may be seen at the Pan-American Exposition will provea fitting demonstration of the complete and thorough manner in which the brilliant discovery of Dr. Nernst has been taken up and pushed forward in America.

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

has the honor to transmit with

FRATERNAL GREETINGS

to

THE INSTITUTION OF ELECTRICAL ENGINEERS

of Great Britain

the following resolutions:

*Whereas*, The American Institute of Electrical Engineers, during the visit of its members to London and Paris in connection with the International Electrical Congress of 1900, and also in connection with the joint meeting immediately preceding the same of the British Institution and American Institute of Electrical Engineers held in Paris on the 16th day of August, 1900, was the recipient of many courtesies and much hospitality from the British Institution of Electrical Engineers;

*Resolved*, That The American Institute of Electrical Engineers herewith respectfully tenders to The Institution of Electrical Engineers of Great Britain its sincere thanks for the many courtesies extended to its members in connection with the above-mentioned visit to London and with the joint meeting of the two Institutions in Paris, both of which have left many pleasureable recollections;

*Resolved*, That a copy of these resolutions be forwarded to the Institution of Electrical Engineers in London, and that a copy of the same be published in the Transactions of The American Institute of Electrical Engineers.

The above resolutions were unanimously adopted at a meeting of the Council of The American Institute of Electrical Engineers, held in New York City, U. S. A., March 22d, 1901.

(Signed) Carl Hering, *President.*

[seal.] (Signed) Ralph W. Pope, *Secretary.*

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INSTITUTION OF ELECTRICAL ENGINEERS.

Founded 1871—Incorporated 1888.

Victoria Mansions,

28 Victoria Street,

London, S. W., 28th May, 1901.

Ralph W. Pope, Esq., Secretary

American Institute of Electrical Engineers,

26 Cortlandt Street, New York City, U. S. A.

Dear Mr. Pope:

The Council has received with very great satisfaction the handsome and generously-expressed illuminated address that your Institute has been so good as to send to this Institution. They desire us to convey to your Institute their

cordial thanks for the address, and to assure your membership that it gave the members of this Institution real pleasure to welcome their American colleagues in London and to join with them in the Paris meeting last year.

The address is to be presented at the Annual General Meeting on Thursday next, and will be shown at our Conversazione in June. To all who took part in our gathering last August it will awaken pleasant memories of much good-fellowship, and will encourage the hope that the bond of international sympathy may grow firmer as years pass by.

We are, Dear Mr. Pope, Yours very truly,

(Signed) JOHN PERRY, *President.*

(Signed) WALTER E. MCMILLAN, *Secretary.*

## OBITUARY.

RICHARD RUSH BRYAN.—Some time during the night of April 9th, 1901, Richard R. Bryan died of apoplexy. His end was sudden and devoid of pain. He spent the evening before with his friends, his bright, cheery laughing self, and in the morning his brave soul had gone to Him who made it.

He was born at Allegheny, Penn., September 30th, 1866, where he received a common school education, which he supplemented after entering business by technical study in a night school, and later, in his determination to reach the front rank of his profession, left a good position with the Westinghouse Electric and Manufacturing Co. to take a year's special course at the Massachusetts Institute of Technology. Shortly after this he came to me as an assistant, staying with me for over two years. He was elected an Associate Member of the INSTITUTE May 15th, 1900.

His wide and detailed information regarding all kinds of machinery was remarkable, his energy inexhaustible. To illness, pain and discouragements he opposed a brave and cheerful front, never murmuring at the trials that few men are called on to bear, but struggling, fighting on till, when success was within his grasp and all he had been striving, hoping for seemed almost his, death came and ended the battle all but won.

He left me about two years ago to enter the field of consulting and contracting engineering in the South, where were many of his friends and relatives, and his venture was a success almost from the start, his restless energy, broad knowledge of machinery, sound business methods, sterling honesty and charm of manner being elements of success that brought him rapidly to the front.

As an evidence of his versatility, he installed a railway for the Westinghouse Electric and Manufacturing Co., after working for some time in their factory, superintended for me the installation of a 60 ton ice plant at Norfolk, Va., set up a storage battery lighting plant at Atlanta, and at the time of his death had nearly completed a coal car cable hoisting plant at Norfolk for the Norfolk and Western R. R. Co. and a blower plant for the Elkhorn tunnel of the same company, besides various other smaller works, all of which were remarkably successful.

He was a true friend, an honest and courteous gentleman, and an earnest Christian. To us who were his friends his death was a loss; to him it could only have meant rest and peace.

THORBURN REID.

NEW YORK, June 18th, 1901.

## Books Received by the Institute.

Central Electrical Stations, Their Design, Organization and Management. By Charles Henry Wordingham, A.K.C. 7in. x 9¼in., cloth, 500 pages, 186 illustrations. London, Charles Griffin & Co., Ltd New York, D. Van Nostrand & Co. Price, $7.50 net.

Contents.—Central Station Work as a Profession, Central Station Supply as an Investment, The Establishment of a Central Station, Systems of Supply, The Choice of a Site for the Generating Station and of the Systems of Supply, Architectural Features of Generating and Transforming Stations, Choice of size and type of Plant and General Design of Station, Boilers, Systems of Draught and Economy of Waste Heat, Methods of Firing Boilers, Coal Handling, Weighing and Storing, The Feeding of Boilers, The Transmission of Steam, Generators, Condensing Appliances, Switching Gear, Instruments, and Electrical Connections, Distributing Mains—Drawing-in Systems, Distributing Mains—Built-in Systems, Various Dielectrics. Distributing Mains—Insulation Resistance and Cost, Distributing Networks, Service Mains and Feeders, Testing of Mains, Recording the Laying of Mains, Meters and Appliances on Consumers' Premises, Standardizing and Testing Laboratory, Secondary Batteries, Street Lighting, The Cost of Production, Methods of Charging, The Regulation of Consumers' Installations, General Organization of a Central Station, The Generating Station. The Mains Department, The Installation Department, The Standardizing Department, The Drawing Office, The Transforming Stations, and Street Lighting, The Clerical Department, The Consumer, The Routine of Main Laying. Index.

Mathematical Drawing and Measuring Instruments; Their Construction, Uses, Qualities, Selection, Preservation, and Suggestions for Improvements, With Hints Upon Drawing, Coloring, Calculating, Sun Printing, Lettering, etc., by William Ford Stanley, 370 pp. with index. Seventh Edition, Copiously Illustrated. Spon and Chamberlain, 12 Cortlandt St., New York.

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## DIED.

Wood:—At Albany, N.Y., April 21st, 1901, Arthur Bryant Wood, of Schenectady, N. Y. Mr. Wood was born at Wellsboro, Penn., June 4th, 1875, and was a graduate of the University of Michigan, class of 1899, with the degree of B.S. (E.E.). He was employed as a draughtsman for two months by the Eddy Electric Manufacturing Co. of Windsor, Conn., and subsequently went to Schenectady. After undergoing three operations for appendicitis at the Albany Hospital, he died of heart failure. He was elected an Associate Member of the Institute January 9th, 1901.

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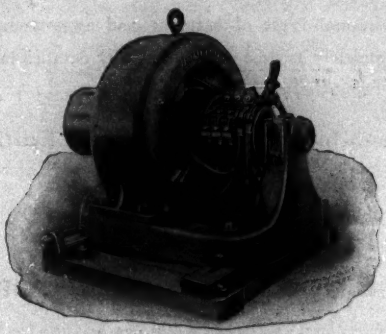

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